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Professor, Mechanical Engineering
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Robotics
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NI LabVIEW
LabVIEW makes me better by making complex
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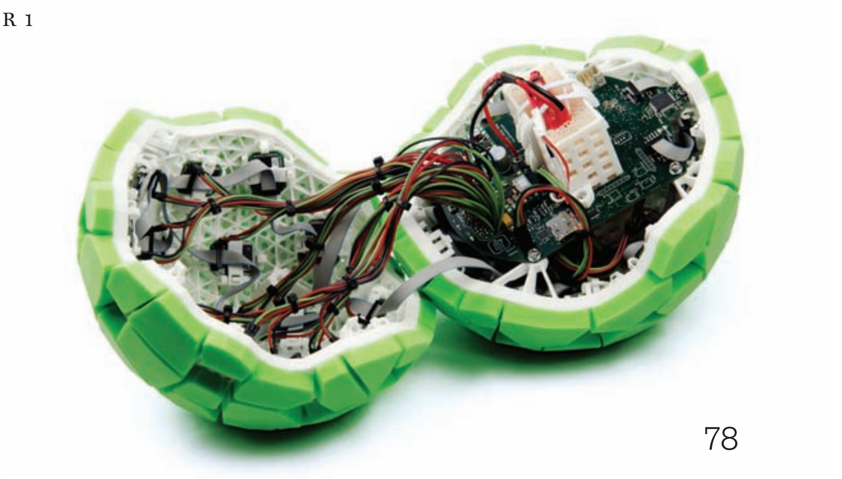

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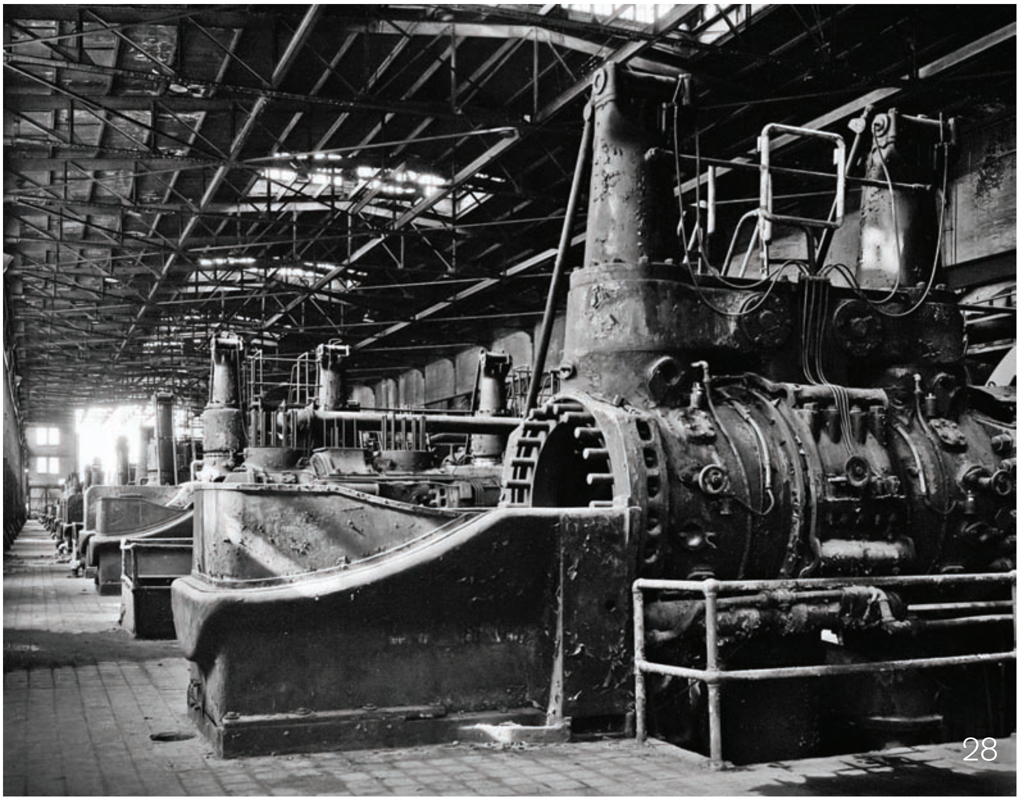

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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

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"A New Chapter for E-Books," November/December 2011

"Do we want a *Wealth of Nations* by Adam Smith that changes with the latest contributions of every new Nobel laureate in economics?"

Thomas Sipe, Grosse Pointe Woods, Michigan

MONEY DOWN THE PIPES Our feature on the source of the controversial proposed Keystone XL pipeline ("Alberta's Oil Sands Heat Up," November/December 2011) prompted a great deal of response, including a comment from **Philip F. Henshaw of New York**, who called it "one of the better articles on the subject I've seen." But he went on to say that we, like "so many paid professionals doing economic analysis of energy questions," had failed to account for all the costs of oil-sands development. "Continuing to expand our economy on fossil fuels will waste money and time on investments that will have to be prematurely abandoned, and will allow many of the worst consequences of climate change. We're already paying a heavy cost for founding our society on dead-end technologies, and we're still proposing to make the problem much worse. I look at that in amazement."

MISTAKES WERE MADE After reading Jon Cohen's look at scientific journals' limited retractions of research that was later debunked ("Public Mea Culpas," November/December 2011), **Peter Belmont of Brooklyn, New York**, imagined a disastrous scenario in which a doctor might prescribe a treatment based on published research, unaware that the results had been (very) quietly retracted by an embarrassed journal. "All proper scientific periodicals should have a contract with those who submit their work that their papers will be subject to cross-reference for withdrawals or challenges," Belmont suggested. "The rush to publish is important to scientific reputation, but it ought to be tempered by a researcher's knowledge that all subsequent reaction to that publication will be immediately available to all readers."

November/December 2011

EULOGY FOR THE PC Many online readers of *TR* felt compelled to respond to Harvard professor Jonathan Zittrain's recent essay "The Personal Computer Is Dead." Zittrain argued that the emergence of app stores means the information we're now "allowed" to access is filtered through a few powerful arbiters in a way that is far more domineering than anything Microsoft would have dared to do in the 1990s, when it provoked an antitrust case. "I too have become alarmed over these trends," wrote **trans**. "This phone/OS lock-in prevents real innovation. We have already

seen two mobile platforms die because of it: Meego and webOS. If this continues, I fear we will be left with only two walled gardens to choose from."

Balderdash, responded **fixerdave**: "You have to factor in the increased number of users. More users today are likely using Linux than were using Windows when Microsoft trashed Netscape. The number of people demanding freedom in their computing experience is increasing, even if those numbers are being drowned out by, well, let's just say 'nontechnical' people who are perfectly comfortable in an app store."

Abdussamad, meanwhile, felt the problem would sort itself out: "No one is stopping another company from starting its own marketplace and offering manufacturers an incentive to add their icon on the desktop. Anyone can do this, given a high enough marketing budget. And I am sure they will—there is just too much money in it!"

THE MORE THINGS CHANGE In "A New Chapter for E-Books" (November/December 2011), Erica Naone described a biology textbook that will update electronically rather than making us wait for the next published edition. **Thomas Sipe of Grosse Pointe Woods, Michigan**, hated the idea: "Do we want a *Wealth of Nations* by Adam Smith that changes with the latest contributions of every new Nobel laureate in economics? I don't fear the e-book revolution. I celebrate it. But a textbook with 'lifetime access' that changes like a cinematic shape-shifter evokes, ironically, some of the most pedantic and turgid qualities of ultraconservative, antiscientific medieval scholasticism." tr

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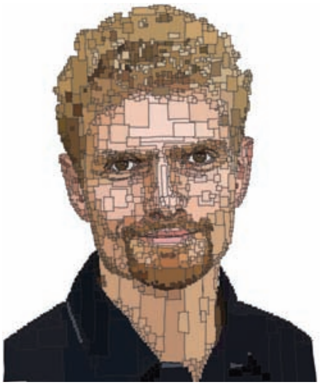


MEDICINE

Defining Experience

A better definition of consciousness will help with tough ethical choices, says Morten Overgaard.

Much empirical research is devoted to the "hard problem," as the philosopher David Chalmers has put it, of why human information processing is accompanied by the subjective experience we call consciousness. Solving this problem has real clinical consequences for some patients *(see "The Mystery Behind Anesthesia," p. 60)*.

Researchers typically distinguish between the contents of consciousness and its levels. The contents of consciousness are our subjective experience, such as the taste of coffee. It is sometimes said that an experience ranks among the contents of consciousness if there is "something it is like" to have it. If there is something it is like, say, for a bat to have a sonar sense, then that sense is part of bats' consciousness.

Levels of consciousness, on the other hand, have to do with outward signs of a person's total or background state of awareness. Our understanding of these levels directly affects patient care. Today, we recognize three distinct "stages" of degraded consciousness based on a person's physical reactions. A person in a coma cannot be aroused and is considered unconscious. A person in a vegetative state is also unconscious but has signs of a normal sleep-wake cycle and may even appear to waken. Finally, a person is said to be in a minimally conscious state if an outside observer can see intermittent signs that he or she has some understanding of self or environment.

Yet these outer signs don't capture the core phenomenon of consciousness—subjective experience. To properly care for patients, we arguably need a new classification system more closely related to the contents of consciousness. Recent research is suggesting how we might create one. In one study, Adrian Owen and coworkers in the U.K. asked a patient in a vegetative state to think of certain mental images ("Imagine playing tennis" or "Imagine visiting the rooms in your house"). The resultant brain activation was no different from that observed in healthy control subjects, suggesting that some people in a vegetative state are more conscious than we realize. This technique was used to communicate with four out of 23 vegetative patients who would otherwise have been considered unconscious; they thought of tennis for "yes" and being in their house for "no."

Over the last few years, brain imaging studies like Owen's, along with other projects, have improved our tools for studying consciousness. While still indirect, such methods are still better than trying to assess consciousness by measuring something altogether different, like outward signs of contact with the world. A new classification system might help us predict which patients will benefit most from rehabilitation. It will certainly affect how we make the ethical decisions that arise when caring for patients with degraded consciousness.

MORTEN OVERGAARD STUDIES THE NATURE OF CONSCIOUSNESS AS LEADER OF THE COGNITIVE NEUROSCIENCE RESEARCH UNIT IN DENMARK.

NICK REDDYHOFF

WEB

Net Worth

Efforts to preserve the Web should make use of the powerful, distributed collaboration it allows, says Kris Carpenter Negulescu.

The challenge of collecting and preserving the Web, or even a representative sample of it, is a daunting one *(see "Fire in the Library," p. 54)*. It is not enough to simply capture the information a website contained, be that text, images, or video. We must preserve something of the experience and activity a site supported. How a site was accessed, who linked to it, and how that changed over time provide important context for critical events such as the recent tsunami in Japan or the events of 9/11, which are relatively distant at the speed at which the Web evolves and leaves data behind. No lone institution can attempt to preserve all that. It will take the commitment of a critical mass of government institutions, companies, nonprofits, and more to ensure the longevity of our digital heritage, nationally and globally.

Current notions of what the Web represents socially, culturally, politically, economically, legally, and even scientifically vary depending on where you happen to live in the world. The value systems to which you subscribe shape what you see in the Web. This is an advantage when thinking of how to preserve the diversity of experience online. Unfortunately, many factors

work against the cross-cultural collaboration needed to preserve the Web's diversity at scale. Local legislation can hinder attempts to share information; companies can fear negative commercial consequences from providing access to their data; and limited budgets constrain the few organizations, such as the Internet Archive, that are dedicated to preserving the Web.

In a perfect world, this would not be the case. Individuals, governments, universities, libraries, and corporations would all work to preserve the world's most vibrant cultural medium. Imagine for a moment an approach to preservation that builds on the fundamental strengths of the Internet itself—distributed, ubiquitous, relatively inexpensive, not easily quelled or manipulated by any single actor. "Netizens" from around the globe would work to build a unified Web archive spanning cultural, political, and commercial boundaries. Subject-matter experts would ensure that their spheres were adequately represented; others would confirm that a representative sample across all domains was being collected.

The result would not be a single resource but, rather, a distributed collection of them. We would need the equivalent of search engines for this Web of the past, and new tools to mine, graph, and study it.

Making this happen would require a global willingness to exchange data for long-term preservation. Is this too far-out to imagine? Perhaps. But such coöperation is appearing within international research communities and cultural groups in both Europe and the United States. This work creates a foundation we can build upon. Only by encouraging this type of collaboration among like-minded communities can we hope to preserve any significant slice of the Web. The future does not afford anyone the luxury of the unlimited time, funds, computing power, and storage capacity that would be needed to do it alone.

KRIS CARPENTER NEGULESCU IS DIRECTOR OF WEB ARCHIVING AT THE INTERNET ARCHIVE, A NONPROFIT INTERNET LIBRARY THAT PRESERVES DIGITAL CONTENT.

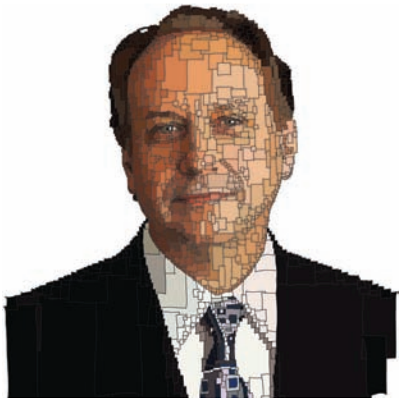
MANUFACTURING

Making Revolution

The U.S. can compete with China if it gives factory workers smarter tools, says Rodney Brooks.

In October I joined a distinguished panel at the National Academy of Engineering on the future of manufacturing. One argument presented was that the United States needed to find things that it alone could make, ceding other manufacturing to China.

That wrongheaded thinking pervades discussion about the role of manufacturing in America's future. It ignores huge opportunities by equating advanced manufacturing with manufacturing advanced stuff—things like jet engines that only big companies buy.



The United States cannot afford to stop making ordinary stuff—things we buy at the store, like running shoes and cell phones—and hope to compete by doing only design and innovation. Making more competitive products relies on a tight intertwining of design and manufacturing *(see "Can We Build Tomorrow's Breakthroughs?" p. 36)*. Once we outsource to manufacturers in China, they soon offer us design, too, since they are the ones who can most easily change existing product lines or introduce new ones. The contractor soon becomes an innovator in its own right, recruiting local designers to work with its now expert manufacturing engineers and get results faster than any U.S.-based design team. We saw this movie already in Japan and then in Korea, and now it is showing in Taiwan and China.

Making ordinary stuff domestically keeps transportation costs low and creates short supply chains that respond quickly to customers. More significant, it offers the chance to empower factory workers with information technology, just as the personal IT revolution has empowered office workers.

Thirty years ago, most office workers could not control information flow. They received paper memos and reports printed from mainframe computers. Distributing your own memo was a multiperson process; changing a printout took weeks and a dozen people. The PC changed all that. By the economic boom years of the late 1990s, any individual office worker could produce memos and automate simple tasks, using tools such as e-mail and spreadsheets.

The same democratization of information flow and automation has yet to come to manufacturing. By analogy, our current industrial systems and robots are mainframes, and advanced-manufacturing innovation is concentrated on supercomputers. But the building blocks needed to create the PCs of manufacturing abound; these will be the robotics and automation tools for the masses. We can create tools for ordinary workers, with intuitive interfaces, extensive use of vision and other sensors, and even the Web-based distribution mechanisms of the IT industry.

It was hard to imagine secretaries becoming "programmers" in 1980, and it is hard to conceive of ordinary U.S. factory workers becoming manufacturing engineers. But people who once would have been called secretaries now routinely use spreadsheets, typeset publications, and move money globally. We need to create the tools to similarly empower our factory workers. tr

RODNEY BROOKS IS PROFESSOR EMERITUS OF ROBOTICS AT MIT AND FOUNDER OF THE MANUFACTURING STARTUP HEARTLAND ROBOTICS.

Building the Future

Tomorrow's breakthroughs will demand the revival of American manufacturing.

Why should the larger world care about the decline of manufacturing in the United States?

That it *has* declined is not in doubt. Between 2000 and 2010, the number of jobs in American manufacturing fell by 34 percent; it was, in all, a loss of six million jobs. Much of that labor was not eliminated by declining demand for goods, or by automation of production, so much as it moved. The United States is no longer the largest manufacturer in the world; that honor now belongs to China, which manufacturers 19.8 percent of the world's goods. By contrast, last year the United States' share was 19.4 percent.

Each of those lost jobs bears the weight of its own story; and yet, as *Technology Review*'s editor, David Rotman, writes in the first story in this special issue on manufacturing *("Can We Build Tomorrow's Breakthroughs?" p. 36)*, "If you believe that … moving manufacturing to places where production is cheap makes companies more competitive, such a shift might not matter beyond its implications for the U.S. economy and its workers." But in fact, as our stories show, a healthy manufacturing sector in the United States is important not only to Americans but to everyone.

That's because "it turns out it's not necessarily true that innovative technologies will simply be manufactured elsewhere if it doesn't happen in the United States," Rotman warns. He argues that the United States, for a variety of reasons, remains the most prolific inventor of new technologies, but that the shrinking of American industrial capacities makes it less likely that those technologies will be built and broadly used.

Photonic integrated circuits (analogous to electronic integrated circuits, except that information signals are in the form of light) are an example. The development of integrated photonics was mostly abandoned by American optoelectronics manufacturers when, seeking lower production costs, they moved manufacturing outside the United States in the early part of the last decade. There, "differences in manufacturing practices meant that producing integrated photonic chips was not economically viable," writes Rotman. A technology that had been expected to make computers faster and more easily integrated into the photonic telecommunications networks was not widely adopted.

Unlike the information technology industry, where a device like the iPhone may be "designed by Apple in California and assembled in China" (for less than $7 of the total cost), most industrial sectors cannot easily separate research, development, and design from production. Often it is only by manufacturing stuff that companies learn what inventions are practical and viable to produce next. Novel production technologies such as 3-D printing, sometimes called "additive manufacturing" *(see "Layer by Layer," p. 50)*, will allow companies to do things they could not do before: rapidly make prototypes, or construct complicated parts from expensive materials like titanium with little waste. But unless they understand manufacturing, companies will likely not be able to fully exploit the new opportunities.

Perhaps the example that best illustrates the importance of innovation to manufacturing comes from China. As Kevin Bullis explains in "The Chinese Solar Machine" (*p. 46*), "Ten years ago, solar panels were made mostly in the United States, Germany, and Japan … Today Chinese manufacturers make about 50 million solar panels a year—over half the world's supply in 2010—and include four of the world's top five solar-panel manufacturers." Leading them is Suntech, which achieved its prominence not through cheap labor; solar cells are made with expensive equipment and materials, and labor accounts for just a small fraction of the costs. Suntech has succeeded by "tweaking manufacturing processes to decrease the cost of manufacturing conventional solar panels." The company is now commercializing a radical new technology. Its expertise in manufacturing suggested a simple, low-cost way to adapt a "horribly complicated process," hitherto a lab curiosity, to the assembly line. The new technology "allowed the company to reach efficiency levels and cost reductions that [the solar industry] … had set as targets for 2020."

Suntech's technology was developed at the University of New South Wales and at Suntech's own headquarters in Wuxi. But more genuinely novel technologies are developed in the United States than in China. Most innovations must be manufactured to have any impact. Those innovations will require comparable innovations in manufacturing if they are to be produced efficiently. In some cases, the innovation—making something scarce or expensive common or cheap—will be the manufacturing process itself. That's why American manufacturing matters.

In our July 2011 *Business Impact* special report on advanced manufacturing, we analyzed some of the brightest ideas for reviving U.S. manufacturing. Read that, and this issue, and write to me at jason.pontin@technologyreview.com and tell me what you think. *—Jason Pontin*

MARK OSTOW

PHOTO COURTESY OF INDRA

The world of health-care information is moving online, as governments around the world wrestle with how best to manage and improve the health care of their citizens efficiently, effectively, and securely. And Spain is one of the countries leading this effort.

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21ST CENTURY HEALTHCARE:

FROM E-HEALTH TO PERSONALIZED MEDICINE

Spain began its electronic health record (EHR) initiative in the region of Andalusia, implementing EHRs for 8 million people. This effort has since been expanded to other regions of the country, and the regional health records are now being integrated at the federal level. By 2010, more than 95 percent of primary health-care providers across Spain had used the electronic records.

In 2005, the Spanish government began implementing electronic prescriptions as well, and by 2010 more than 250 million prescriptions were being submitted electronically to pharmacies, placing Spain among the top nations in the world for utilization of these technologies. In the regions where these e-prescriptions are employed, visits to primary care physicians have decreased by about 15 percent. "Years ago, a chronic patient had to go to the pharmacy every week, and had to go to the primary care doctor just to get that weekly prescription," says Pablo Rivero, director of international e-health development for the Spanish Association of the Information and Communications Technology Industry (AMETIC in Spanish). "Now, the patient can simply go directly to the pharmacy." This change has saved significant cost as well as time.

Managing health-care expenses is a key goal of the Madrid-based consulting company everis; everis is one of the top two companies in Spain in experience with EHR and personal health records, and its solutions cover more than 20 million users. The company's engineers are now working to improve chronic disease management. "Chronic patients consume about 50 percent of the global health budget," says everis business director Santiago Martín.

But the management of different diseases demands different plans, so everis has developed solutions for a number of tasks. First, its software segments a population by sufferers from each disease to be managed, such as diabetes, cardiovascular disease, and lung diseases. Then, for a given disease, the software classifies the population further, depending on the level of care required, and defines the care needed and the technology solutions that can help meet those needs. For instance, one diabetes patient may require only an interface that allows her to upload her weight daily; this can be integrated with a tablet or mobile phone. A more seriously ill patient may require additional technologies, such as advanced sensors for evaluating health outcomes. Martín explains that this segmentation avoids the expense of automatically installing a wide range of health-care technologies in every patient's house.

Everis began implementing its telemedicine and chronic-care solutions in Spain in 2011, and is working with public health administrations to determine the level of cost savings. Martín says thus far the range of savings for chronic patients is 20 to 40 percent over traditional care.

Indra is also investigating the management of long-term chronic patients through a new center in Toledo, near Madrid. The company's engineers are working with the local health-care agency to define the resources and services its patients need, along with the most useful interfaces for the patient and health-care provider. A pilot project involving some 80 thousand individuals will soon be rolled out.

In Andalusia, the region is moving toward the beginning of the next stage, implementing access to electronic health records on mobile devices. The care providers in an ambulance, for example, will be able to access a patient's records via a tablet or mobile phone, incorporate the information into the patient's care, and then update the record for the hospital.

According to Rivero, the key to Spain's success has been the integration of clinicians into all levels of planning: "It's most important to involve health professionals from the very beginning. It's not a 100 percent technological project; it's a change in the process of how health care is delivered."

Madrid-based Oesia has developed specialized software for hospitals and regional and federal health-care administrations, and is moving into the realm of artificial intelligence with a computerized clinical guide. As the doctor types information about a particular patient's condition, for instance, the guide may suggest that a certain scan is not necessary, based on the experiences of other patients. The doctor can then accept that decision, or override it and explain why, leading the system to learn a new pattern.

Among other tasks, the software will be able to synthesize the data from existing patient records, and point out why a particular medication may conflict with the patient's other medications. "The doctor still has the final say," says Arnaud Marivain, director of the Oesia health business unit. "But in an emergency, or perhaps if someone is tired, there can be mistakes. This will help ensure the security of the patient."

This product has been in development for the past year and should be out by the end of 2012.

TRANSFERRING EXPERIENCE OVERSEAS

The Spanish government and Spanish companies are taking their experience in e-health overseas, according to Rivero. "We believe that international collaboration is key for e-health development, to share information and best practices and to create a real network of international collaborators," he explains.

Madrid-based Indra proposed to develop and operate a comprehensive system for Bahrain's entire national health-care system network over the course of the next 11 years. The proposal was accepted based on the company's IT experience in the Spanish health-care system. The first step, says Diego García, Indra's director of health, will involve creating and sharing electronic records and clinical and administrative management systems. The second will include adding e-health functionalities such as telemedicine.

In addition, Indra is working with the European Space Agency (ESA) on a telemedicine project in sub-Saharan Africa; the ESA is involved in projects that expand the reach of the agency's space technology (such as satellite communication) here on Earth. The feasibility study began in Senegal, focusing on basic needs such as the tools for videoconferencing, including a satellite dish, a modem, and electricity (using renewable energy such as wind or solar if necessary). The prototype will allow health-care providers to confer with clinicians around the world, provide a model for e-learning, and facilitate EHRs. The results of the basic needs study were presented in the fall of 2011, and the pilot program has begun in Senegal and Kenya.

> "We believe that international collaboration is key for e-health development, to share information and best practices and to create a real network of international collaborators."

GMV has also developed telemedicine for overseas communities, as part of a comprehensive platform for telemedicine that can range from the most simple configuration—a face-to-face consultation via webcam between a rural or homebound patient and a distant doctor—to a complex system that allows data from any type of device to be transmitted and reviewed. This project is the latest for the engineering company, which has decades of experience in the aerospace sector; based on its experience with NASA and the ESA, the company has applied its engineering expertise to health care in products including medical simulations and EHRs.

GMV has set up a telemedicine platform at a soccer stadium in Cartagena, Columbia, which is networked with five hospitals; the company is now expanding in Latin America and Africa.

Though the eventual goal is to offer such services in Spain (and other developed countries) as well, particularly in intensive-care units where there's a dearth of specialists and a need for immediate specialized care, Carlos Royo, director of business development, expects this will take off first in poor countries. "It's a paradox, but it's actually cheaper and more efficient to jump to the best, most advanced technology there," Royo points out. It's cheaper than, for instance, building a new hospital, even as telemedicine can afford patients a high level of care.

"In the past, I used to talk about the cost of telemedicine. Now I talk about how quickly a government will receive a return

Advances in e-health and telemedicine will enable higher quality and more cost-effective health care.

PHOTO COURTESY OF INDRA

on investment," through savings in transportation costs and in overall improved care for citizens, Royo continues.

PERSONALIZING MEDICAL CARE

The adoption of EHRs facilitates the move towards personalized medicine, points out Indra's García: "We believe that personalized medicine will be used in the future—and what's required is IT." Indra is participating in research projects that examine how health records software could gather all relevant information, including the patient's genetic profile, to tailor a particular diagnosis or treatment. The company has also initiated research into personalized medicine, beginning with an oncology project that analyzes samples and data from 1,000 patients suffering from two types of cancer.

Part of the hope for personalized medicine is to fulfill the promise of matching the correct treatment to every patient. Not every patient will respond to every option, so clinicians at times cycle through a number of potential medications, or combinations of medication, before hitting on one that works.

In response, Vivia Biotech has developed a technology that evaluates the most popular combinations of drugs to treat blood cancers (leukemias, lymphomas, and myelomas). "In blood cancer[s], doctors always give a cocktail of drugs to treat a patient, but there's nothing on the market to predict how the patients will respond to those four or five drugs," says Juan Ballesteros, chief scientific officer. "We're the first to do that."

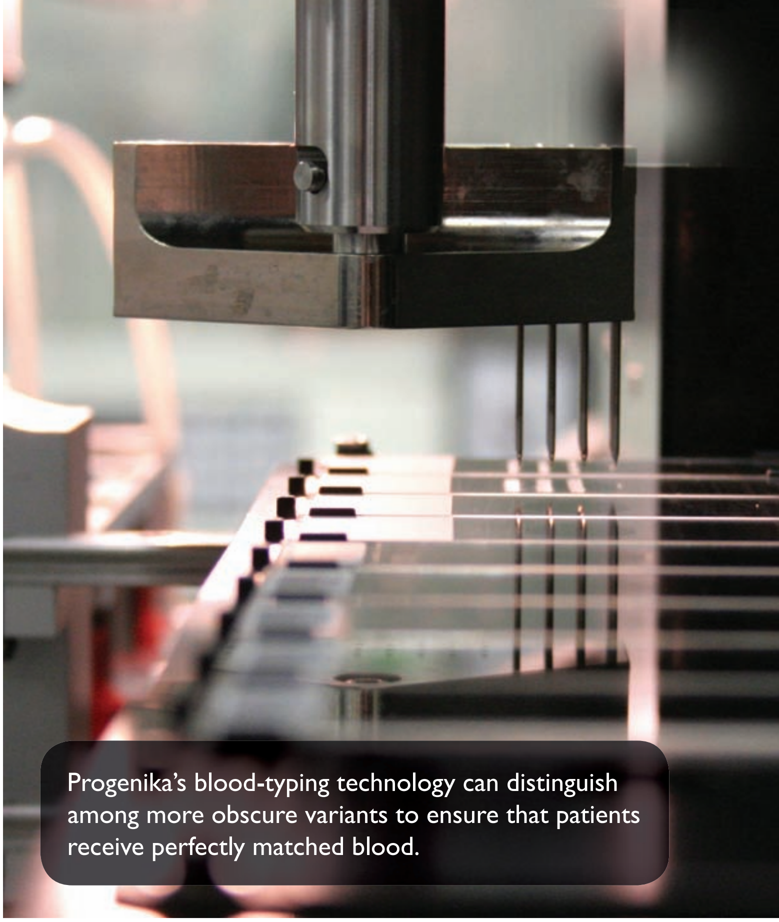
The company's technology, called ExviTech, consists of a platform that can rapidly analyze thousands of biological samples (such as blood samples in combination with medications) in 48 hours. For blood cancers, Vivia Biotech has taken the 18 most popular drug protocols already in use. The patient's blood is treated with each medication combination, which is then ranked by how many tumor cells that protocol kills. Says Ballesteros, "Our hope is not to cure the disease, but to reduce it to being chronic, by quickly finding the right drugs that kill the most tumor cells."

The system is undergoing validation testing in Spain and the United Kingdom. The results are positive, according to Ballesteros—though yet unpublished—and as a result one regional health-care agency in Spain has agreed to initiate a pilot project for all diagnosed blood cancers. Though a test might cost $1,000, the savings it offers could leap to the tens of thousands by avoiding unnecessary and expensive drugs. Its cost-effectiveness will also be evaluated during the partnership with the health-care agency, and Vivia Biotech expects the tests to be on the market in 2012.

Barcelona-based AB-Biotics has also developed a technology to determine a given patient's response to drugs, and has focused on those used most widely to treat psychiatric and neurological diseases.

A DNA chip called Neurofarmagen analyzes the patient's saliva for genetic variations—published in the scientific literature or researched at the company's laboratory—that indicate responses to different drugs. "Some of the variations have to do with the metabolism of the drug, or with the therapeutic target, or with the patient's own biochemistry that could affect the intake and processing of that drug," says CEO Miquel Angel Bonachera.

The company launched its first product, Neurofarmagen, in 2010; it is used for depression, schizophrenia, bipolar disorder, and epilepsy. Further products include Neurofarmagen Epilepsy and Neurofarmagen ADHD. Because of their success in Spain, AB-Biotics is preparing a plan to sell these products abroad, first targeting the U.S. market.


Progenika's blood-typing technology can distinguish among more obscure variants to ensure that patients receive perfectly matched blood.

REFINING BLOOD TYPES

Current tests define blood type as A/B/O and Rh positive or negative, but some racial groups share a variety of more obscure variants, explains Antonio Martinez, CEO of Bilbao-based Progenika. African and Asians, for instance, might be negative for more rare antigens. These do not cause a problem when someone needs a single blood transfusion and receives antigen-mismatched blood; chronic patients, however, will eventually develop antibodies and suffer allergic reactions if the blood donor is not an exact match. Most blood banks currently accept the fact that some patients will live with these antigen-induced complications. Says Martinez, "We want to avoid this problem by supplying patients with the perfectly matched blood from the very beginning."

So Progenika developed a DNA chip to identify whether a patient or blood donor is positive or negative for these blood types (their names include RHCE, Kell, Kidd, and Duffy). The test identifies 23 single-nucleotide polymorphisms, or SNPs, and labels them with fluorescent molecules. The DNA blood-typing chip, available since 2008, has already been adopted in blood banks across Europe.

For the U.S. market, Progenika identified SNPs related to sickle-cell anemia. The company has already begun selling in the U.S., and recently signed an agreement with Novartis to sell Progenika products in the U.S. The company is now utilizing the same technology to identify markers for cancers, beginning with prostate cancer.

UNCOVERING TRACES OF DISEASE

Another hope of advanced personalized biotechnology is that new techniques will employ genomic sequencing to detect early markers of a disease, or a patient's genetic predisposition to a disease.

Madrid-based BlackBio developed a DNA biosequencing technology that improved the speed and accuracy of sequencing, then moved into the realm of diagnostics. Instead of focusing on a patient's entire genome, BlackBio targeted a handful of SNPs that indicate a patient's likelihood of, for example, developing Type 2 diabetes. Says Gemma García, deputy general manager, "This is quite an important approach for personalized medicine. If you have a high genetic risk of diabetes, you can take preventive steps: change your diet, exercise, try not to gain weight, get your blood pressure under control." The test is done using a simple oral swab. BlackBio began validating the kit with a hospital in Madrid in September 2011.

In addition, BlackBio is teasing out the identification of a variety of diseases. Sepsis, a whole-body infection, can be both fast acting and deadly. Traditional microbiology to determine the source of an infection can take from 48 hours to a week, but the diagnostic kit developed by BlackBio can identify the bacterial source of an infection in only eight hours.

Two Catalonia-based companies, Oryzon and Reig Jofré Laboratories, the former a specialist in biomarkers and early diagnosis and the latter a larger, more traditional pharmaceutical company, have teamed up to offer a minimally invasive test to predict the occurrence of endometrial cancer. This cancer, after breast cancer the second most common among Spanish women, can appear at the same time as menopause, and a woman's irregular bleeding could result from either state. "Ninety-five percent of the time, the bleeding is purely natural," explains Ignasi Biosca, CEO of the Reig Jofré Group. "But in five percent of the cases, the bleeding is related to endometrial cancer. It's important to catch that five percent."

Current tests demand a multistep process and are both expensive and invasive, involving sampling the uterine wall. And Carlos Buesa, CEO of Oryzon, says that "clinicians wanted something simple that could be done on the patient's first visit," without anesthesia. In response, the companies developed a test to evaluate genes found in the mucus on the uterine lining. Following a swab test, the technology can pick up the markers of five genes that are over-expressed in the presence of endometrial cancer.

Oryzon and Reig-Jofré have conducted a clinical trial with 16 Spanish hospitals, comparing the swab test to actual results of the current multistep diagnostics for tissue samples from 500 women. The results, presented in September 2011, demonstrate 97% accuracy and compare favorably to current techniques, but these are available in a dramatically shorter time frame and at a significantly reduced cost.

Buesa says that Oryzon's first product showcases the company's promise in diagnostic and personalized medicine, as the biomarker discovery platform demonstrates. Buesa continues, "We want to become a leader in molecular diagnostics, with specialization in genomics, proteomics, and bioinformatics."

PHOTO COURTESY OF PROGENIKA

to market

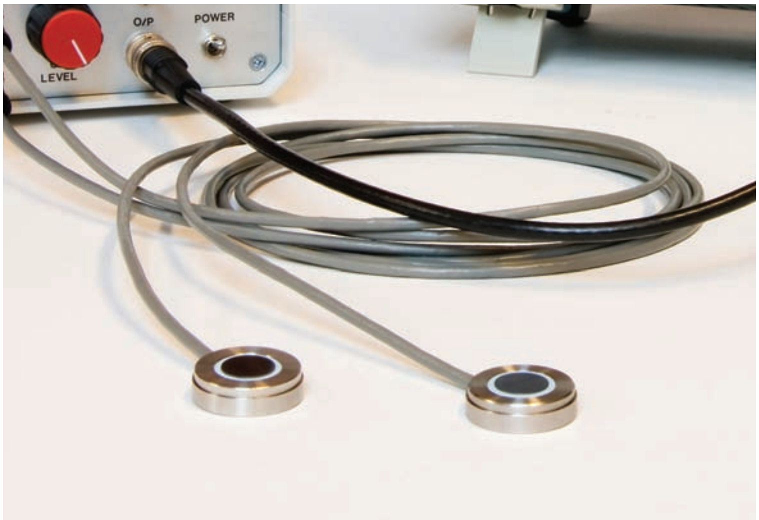
NEST LABS

ENERGY

Room Temperature IQ

THIS SMART thermostat, from a company founded by former lead developers of the iPhone, programs itself by noting what temperatures a homeowner sets it to over the course of a week. Temperatures are then maintained as efficiently as possible, in part by keeping tabs on the weather forecast via Wi-Fi and by using motion sensors to detect when the home is unoccupied, so it can be allowed to become colder or warmer than usual. Energy usage can be monitored online or with a smart phone.

Product: Nest Learning Thermostat **Cost:** $250 **Availability:** Now
Source: www.nest.com **Company:** Nest Labs



BIOMEDICINE

State of the Heart

THESE electrocardiogram sensors incorporate the first solid-state electrometers commercially available. Their sensitivity to electric fields means that the conductive gel normally required for ECG sensors is not needed, nor is it necessary to position seven or more leads precisely on the body. Instead, the patient can simply hold a sensor in each hand to get an accurate reading of heart activity.

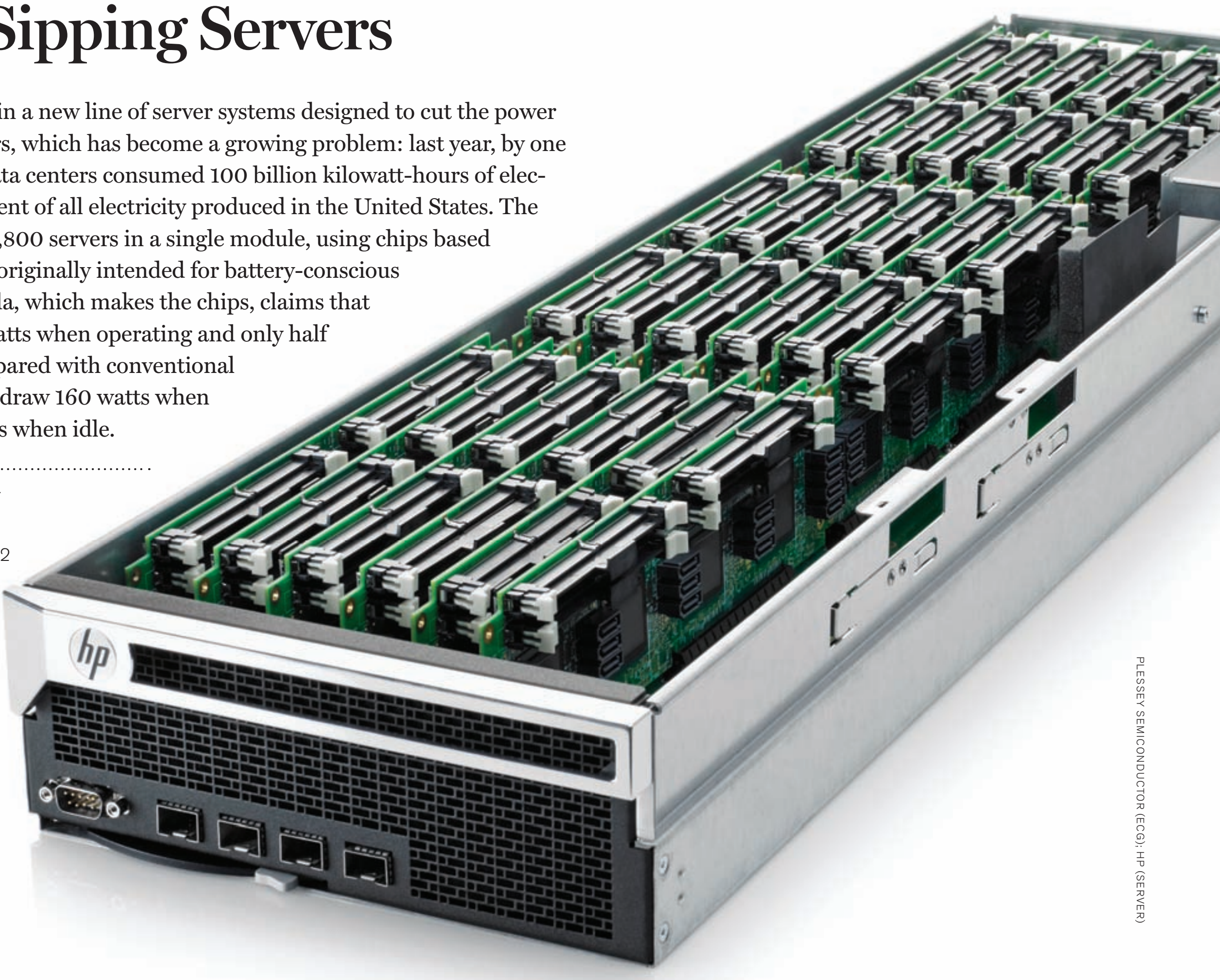
Product: EPIC ECG Sensor **Cost:** \$20 to \$50 **Availability:** Now
Source: www.plesseysemi.com **Company:** Plessey Semiconductors

COMPUTING

Energy-Sipping Servers

THIS IS THE FIRST in a new line of server systems designed to cut the power demand of data centers, which has become a growing problem: last year, by one estimate, American data centers consumed 100 billion kilowatt-hours of electricity, or about 2 percent of all electricity produced in the United States. The system bundles over 2,800 servers in a single module, using chips based on a processor design originally intended for battery-conscious mobile devices. Calxeda, which makes the chips, claims that its servers draw five watts when operating and only half a watt when idle, compared with conventional server processors that draw 160 watts when operating and 80 watts when idle.

Product: Redstone Server Development Platform
Cost: N/A
Availability: First half of 2012
Source: www.hp.com
Companies: HP, Calxeda



PLESSEY SEMICONDUCTOR (ECG); HP (SERVER)

COMPUTING

Blur-Proof Camera

PRODUCING A CLEAR image with a camera requires choosing a particular focal distance, either manually or with an auto-focusing system: objects nearer or farther away will be blurred. In this new type of camera, that need is eliminated thanks to a complex arrangement of optics, sensors, and processing power that captures the color, intensity, and direction of each incoming ray of light. Software can analyze the resulting "light field," allowing photographers to focus a shot that's already been taken and even to create 3-D images of a scene.

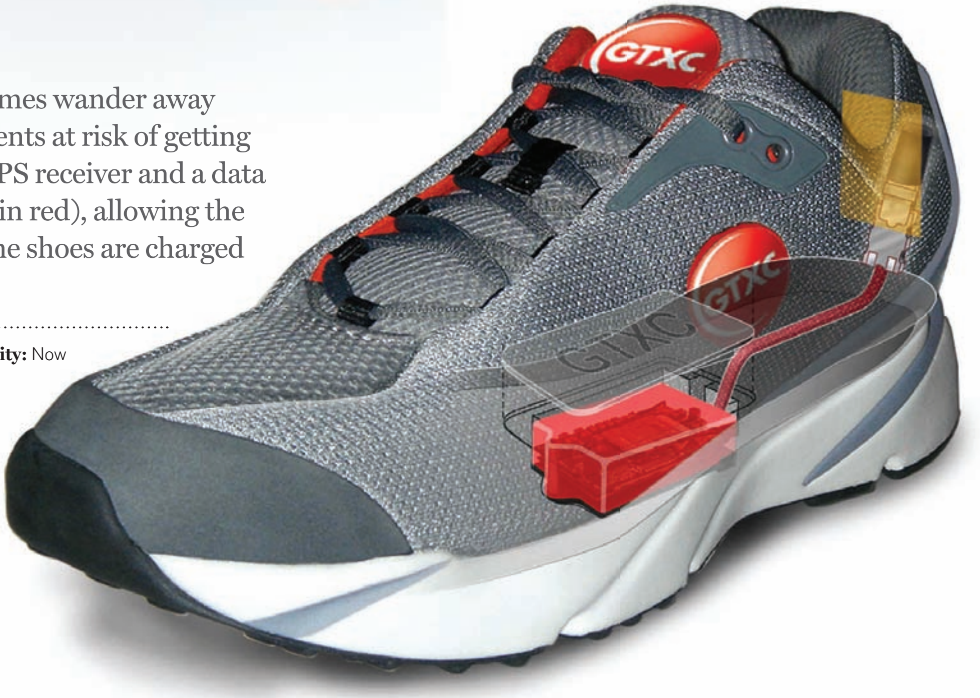
Product: Lytro Light Field Camera
Cost: \$400 to \$500 **Availability:** Early 2012
Source: www.lytro.com **Company:** Lytro

BIOMEDICINE

Tracking Shoes

ALZHEIMER'S patients can sometimes wander away and become disoriented. For patients at risk of getting lost, these shoes have a built-in GPS receiver and a data transmitter in the sole (indicated in red), allowing the wearer's location to be tracked. The shoes are charged via a USB connection in the heel.

Product: Aetrex GPS shoe **Cost:** \$300 **Availability:** Now
Source: www.aetrex.com **Company:** Aetrex



LYTRO (CAMERA); AETREX (SHOE)

COMMUNICATIONS

Bypassing Cellular

IT'S COMMON for smart phones today to fall back from cellular to Wi-Fi network connections. This mobile phone inverts that idea: Wi-Fi supplies primary connectivity for voice calls, but the phone defaults to the Sprint cellular network if no Wi-Fi network is available. The advantages are that users can buy the phone without a contract; service fees are a flat $19 per month. Previous smart phones that allowed voice-over-Wi-Fi calls required a contract with a carrier.

Product: Republic Wireless **Cost:** $200 **Availability:** Now **Source:** republicwireless.com **Company:** Republic Wireless

BIOMEDICINE

Melanoma Monitor

IT CAN BE difficult for dermatologists to correctly identify early-stage skin cancer. To assist them, this device uses a multispectral camera to peer below the skin surface. Using a database of lesions for comparison, the system can recommend that a mole be biopsied. Its accuracy rate is higher than that of a standard examination alone.

Product: MelaFind **Cost:** $7,500: **Availability:** Now **Source:** www.melasciences.com **Company:** Mela Sciences

COMPUTING

External Encryption

FOR THOSE who don't trust cloud storage but still want an easy way to access their data remotely, this paired set of USB dongles provides password-free 256-bit hardware encryption over the Internet. One dongle is left plugged into the user's home or office computer. Plugging the other dongle into a remote computer lets the user access files as if the home or office computer were an attached external drive.

Product: iTwin **Cost:** $100 **Availability:** Now **Source:** www.itwin.com **Company:** iTwin

REPUBLIC WIRELESS (PHONE); MELA SCIENCES (SCANNER); ITWIN (DONGLES)


AlphaWire
EATON
HAMMOND MANUFACTURING
LAMBDA
Amphenol
BELDEN
ebmpapst
FLUKE
Honeywell
Sensing and Control
ITT
OMRON
ELECTRONIC COMPONENTS
TE
connectivity
ST52L
Red
Black
"Great service, rare parts in stock, fast shipping..."
– Ramsey, Newark | element14 customer

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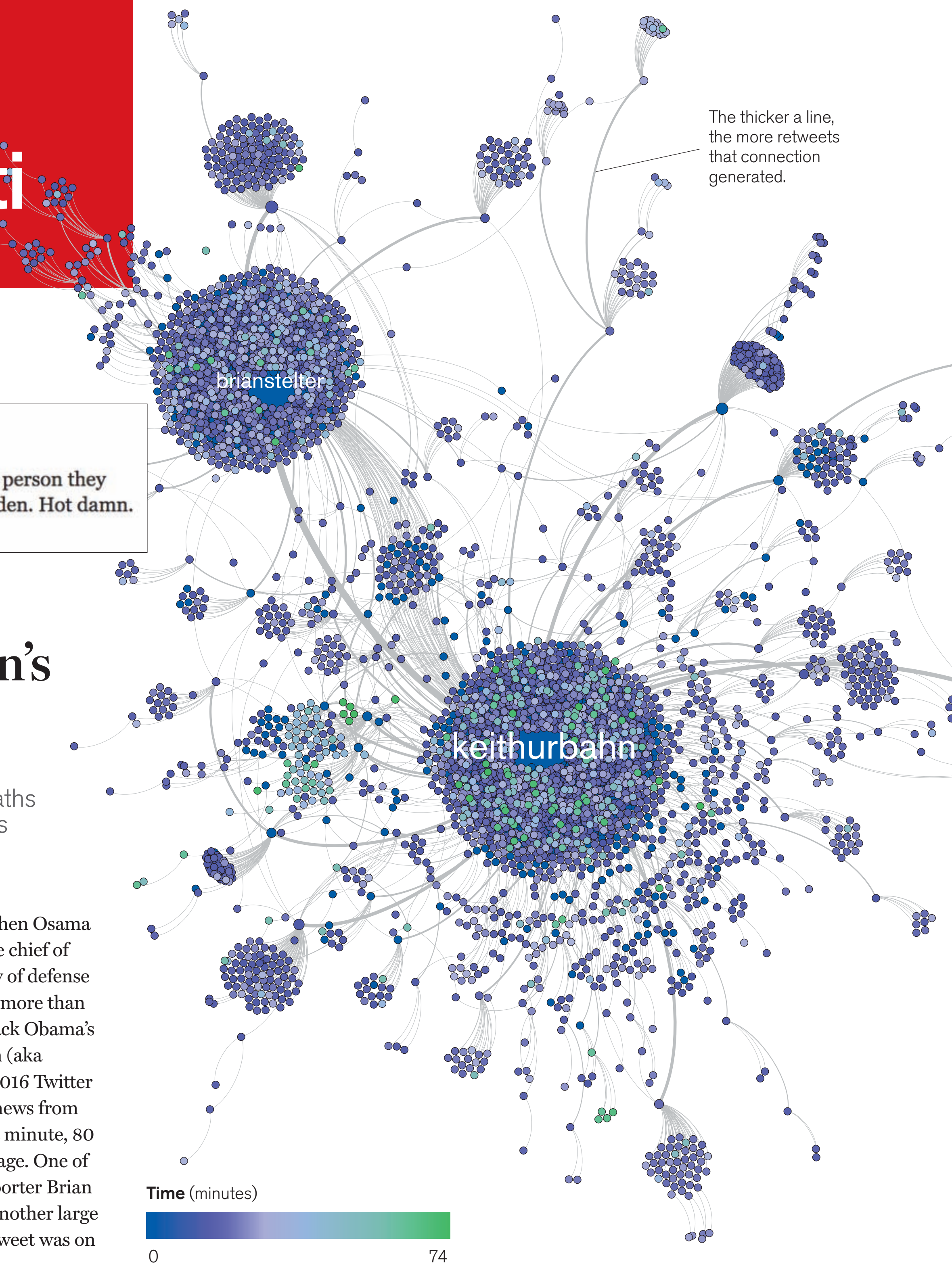
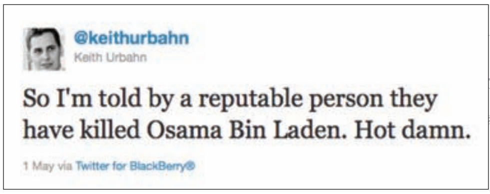



@keithurbahn
Keith Urbahn

So I'm told by a reputable person they have killed Osama Bin Laden. Hot damn.

1 May via Twitter for BlackBerry®

Information's Social Highways

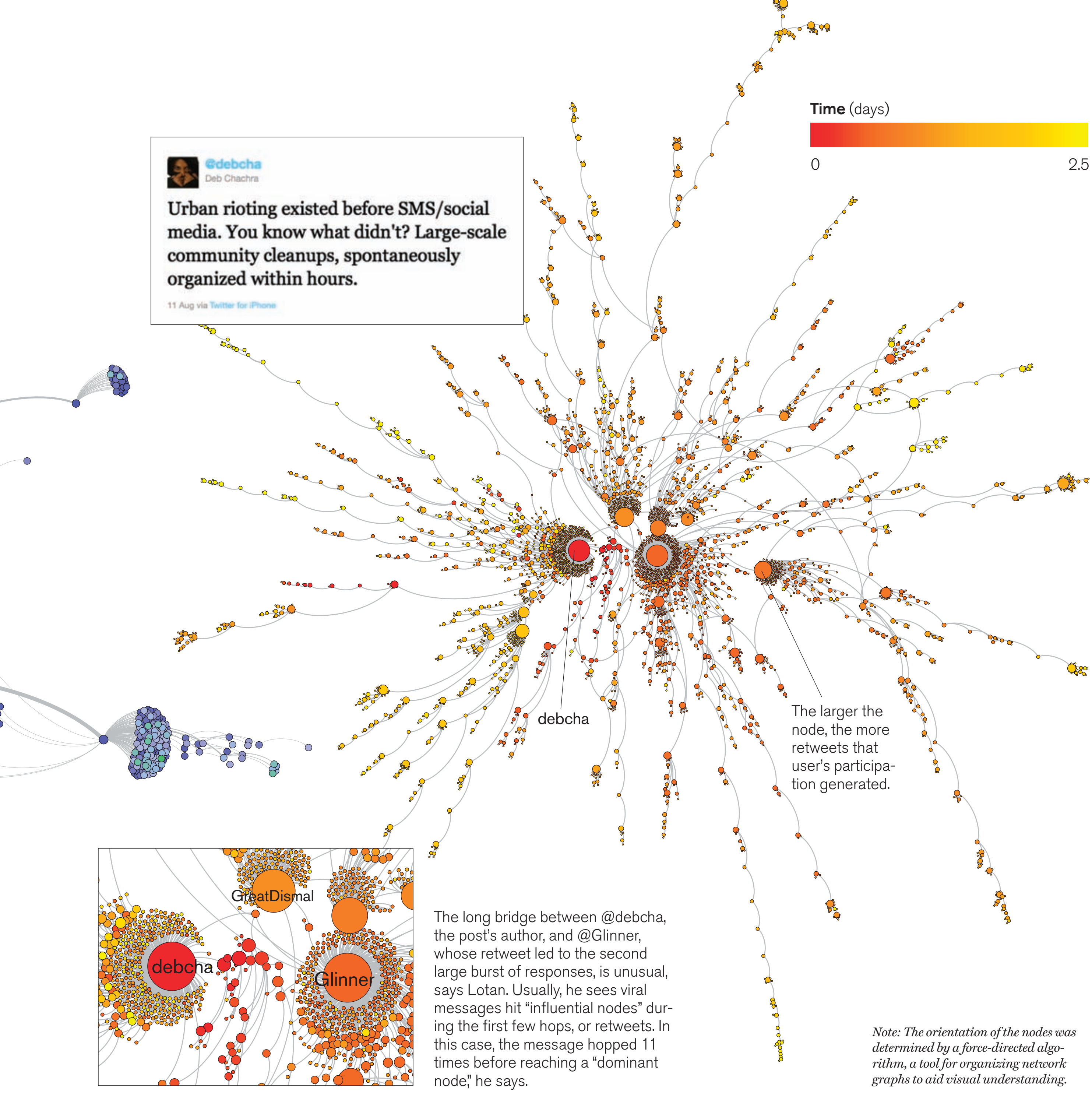
A startup studies the paths taken by viral messages

On the night last spring when Osama bin Laden was killed, the chief of staff to a former U.S. secretary of defense broke the news to the world—more than an hour before President Barack Obama's announcement. Keith Urbahn (aka @keithurbahn) wrote to his 1,016 Twitter followers that he'd heard the news from a "reputable person." Within a minute, 80 people had reposted the message. One of them was *New York Times* reporter Brian Stelter, whose retweet led to another large burst of responses. Urbahn's tweet was on its way to going viral.

There is no recipe for virality, says Gilad Lotan, head of R&D for a startup called SocialFlow, which aims to help clients from the *Economist* to Pepsi more effectively capture attention on Twitter. But the deluges of data that viral tweets generate hold potentially valuable insights into how and why certain things spread beyond their author's network of regular contacts. After the bin Laden event, Lotan took advantage of SocialFlow's access to the Twitter "fire hose," a real-time stream of every tweet, to analyze—and visualize—the responses to Urbahn's post. The results are seen on this page.

Each colored circle, or node, represents a Twitter user who repeated the original message (or posted something similar)

GILAD LOTAN/SOCIALFLOW



The larger the node, the more retweets that user's participation generated.

The long bridge between @debcha, the post's author, and @Glinner, whose retweet led to the second large burst of responses, is unusual, says Lotan. Usually, he sees viral messages hit "influential nodes" during the first few hops, or retweets. In this case, the message hopped 11 times before reaching a "dominant node," he says.

Note: The orientation of the nodes was determined by a force-directed algorithm, a tool for organizing network graphs to aid visual understanding.

and mentioned the author's Twitter handle. The color gradient conveys how long it took for any given message to join the conversation; for instance, bluer circles represent people who took up Urbahn's message within minutes.

Where circles are connected by a line, Lotan is representing the likely pathways along which the message passed. He determined them by analyzing, among other things, when each message was published and the relationships between users (who follows whom).

He made the graph on this page using the same methodology. It shows responses to a tweet, posted by engineering professor Deb Chachra (@debcha), that resonated especially widely during last summer's riots in Britain. This message spread much more slowly than the bin Laden news, and it spread without the involvement of a widely followed journalist. These differences are reflected in the diffuse shape and smaller clusters of the graph. (Examine both graphs in more detail at technologyreview.com/graphiti.)

Being heard isn't always easy in an age when anyone can become a broadcaster. But analyzing and visualizing such data helps SocialFlow guide customers about how, when, and what they should tweet to have the best chance of disseminating their messages widely. *—Mike Orcutt*

Q&A

Prith Banerjee

The head of research at Hewlett-Packard talks about the disruptive technologies that could ensure HP's survival.

Hewlett-Packard is in trouble. Smart phones and tablets threaten to trivialize its status as the world's largest PC maker; cloud computing is destabilizing its server business; printers are no longer seen as high tech. HP's stock price plunged in 2011 as the company groped for a strategic direction.

Part of new CEO Meg Whitman's plan to revitalize HP is to lean more heavily on ideas from the 500 researchers at HP Labs, which is headquartered in Palo Alto, California. They are explicitly tasked with creating disruptive technologies—even if these challenge HP's current business. (For more on disruptive innovations, see Business Impact, p. 65.)

One of Whitman's first steps was to make the labs' director, electrical engineer Prith Banerjee, report directly to her. Banerjee told *Technology Review* IT editor Tom Simonite why disruptive technology is a helpful internal force at HP, not only an unwelcome external one. Among the labs' recent achievements: persuading the company to try low-cost server chips and pioneering a novel memory component known as the memristor.

TR: What's the biggest advance that HP Labs has made during your tenure?

Banerjee: We developed a Richter accelerometer 1,000 times more sensitive than existing sensors. We are working with Shell on using that for energy exploration, combining HP sensors, networking, servers, and software to provide a better picture of existing and alternative energy resources. It will allow Shell to perform more targeted discovery and reduce environmental impact.

Most people associate disruptive technology with startup companies. Why should we believe big companies can innovate?

Startups take research from academia and innovate around how to bring it to market—the execution. The majority of them do very little R&D. A startup could not invent a technology like the memristor: it took us five to 10 years to come up with the right combination of materials and everything else. We are doing fundamental innovation and bringing that to market within the next three years.

What is an example of an idea from the labs that HP is adopting even though it disrupts the existing business?

Project Moonshot, where we launched servers based around low-powered chips with an ARM or Intel Atom architecture like those in mobile devices. Our server business is a very lucrative cash cow; we want people to buy these hunks of metal with large profit margins. But my researchers could see that the future is not heavy number-crunching—it is the tweeting, real-time-updating Zyngas of the world. The architecture we need for that is not a server with a high-performance Intel processor—it's a lot of low-powered processors working together. Eventually the head of our server business said, "We're going to do this."

Isn't it difficult to get leaders in the business units to listen to ideas that challenge their current products?

There are times it's not enough to explain something or show a research prototype. We have a program called Demonstrators to build a product from scratch that really convinces people. For example, we had been researching photonic [networking] interconnects—that use light, not electricity—for several years. But the businesses said it was expensive and couldn't be built. We took a very high-end router that HP makes and changed the [internals] into photonics. When we demoed that, everyone said, "Wow, this is a great innovation."

HP has struggled with smart phones and tablets. How is HP Labs helping the company respond?

We have a mobile team in the lab that works hand in hand with the business; we are passing them the tools to adapt. This is a very fast-moving market, so we can't talk about it in detail. We also are researching areas that HP is not currently working in, and that goes for our mobile team, too.

HP Labs has sites in the U.K., Israel, Russia, Singapore, India, and China. Does that help you find disruptive ideas?

If you are only U.S.-centric, you are missing a lot of opportunities. Let's say you're trying to create a tablet device for India. You would think of the iPad, but out of India's one billion people, only 50 million access the Internet—but 500 million have access to simple phones. Our researchers in India built a hardware device called the Vayu and a whole cloud system to deliver the Web via SMS, called Siteonmobiles. Our researchers in Palo Alto would never have thought of that.

After you joined HP Labs, you consolidated research into fewer areas. Why?

We were working on far too many cool things. We had 150-ish projects, each involving one or two researchers. We felt that we needed to channel the creative minds of these people. If every project would bring together two computer scientists, one chemical engineer, a social scientist, and a physicist, something really cool could happen. tr

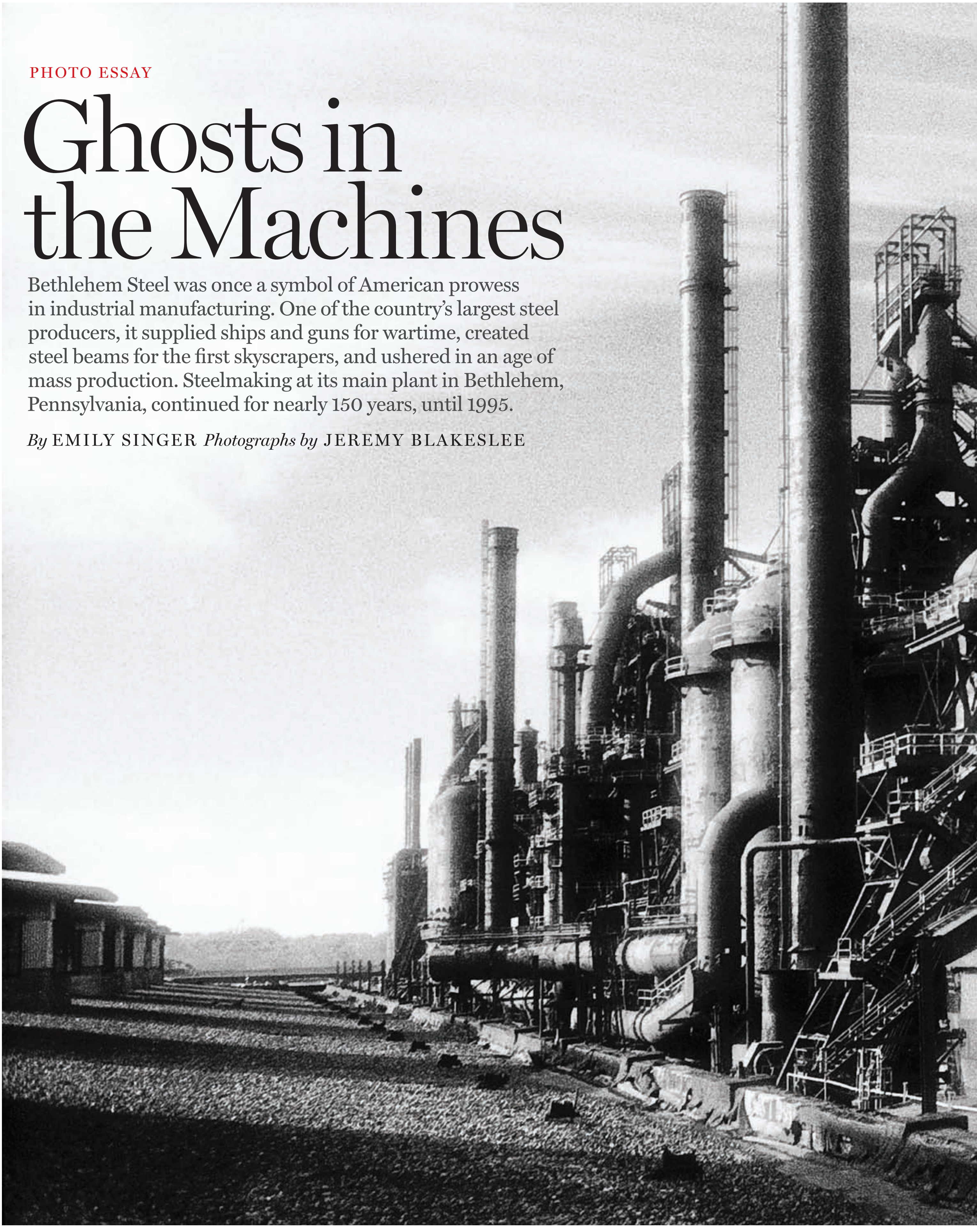
Photograph by WINNI WINTERMEYER

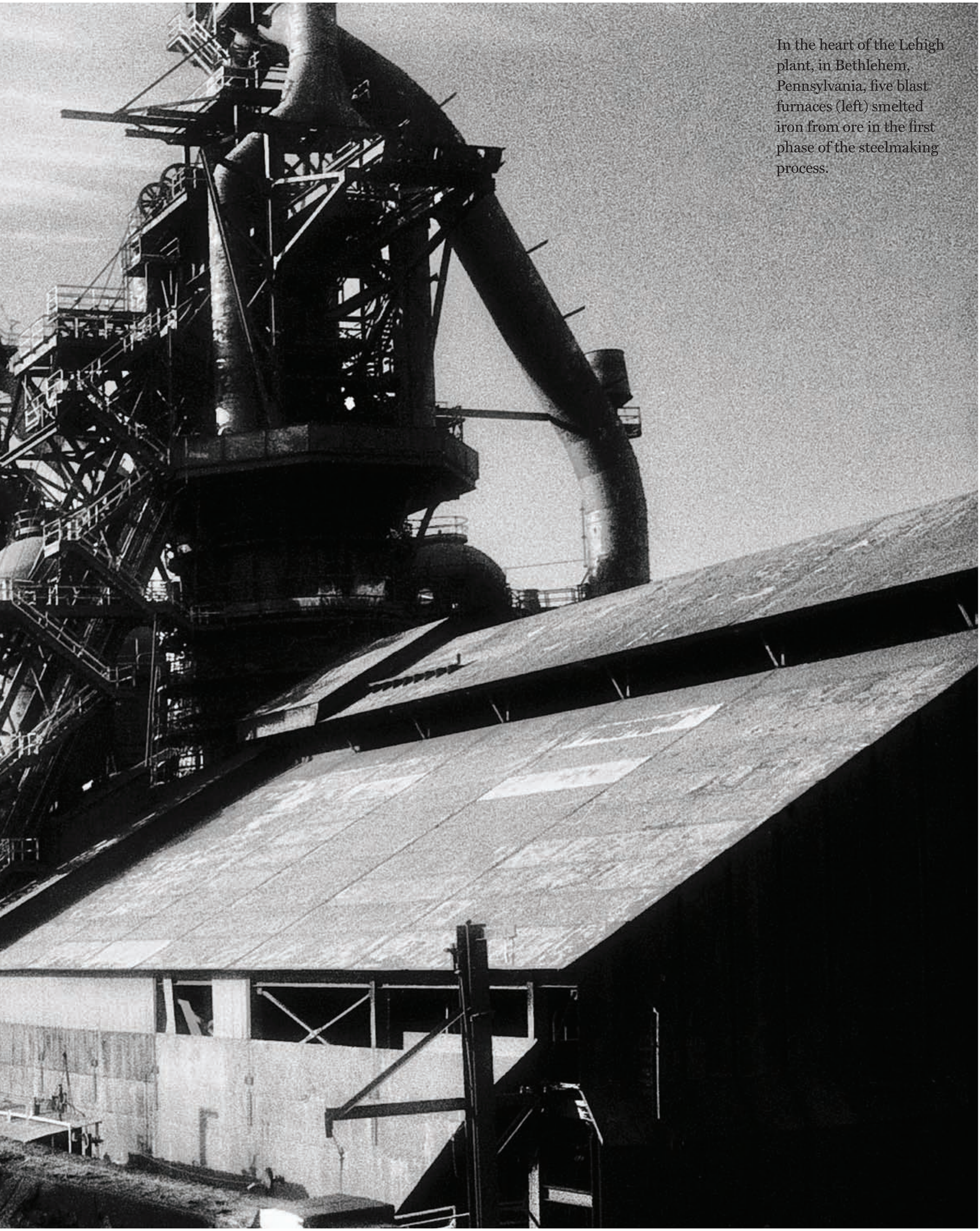
PHOTO ESSAY

Ghosts in the Machines

Bethlehem Steel was once a symbol of American prowess in industrial manufacturing. One of the country's largest steel producers, it supplied ships and guns for wartime, created steel beams for the first skyscrapers, and ushered in an age of mass production. Steelmaking at its main plant in Bethlehem, Pennsylvania, continued for nearly 150 years, until 1995.

By EMILY SINGER *Photographs by* JEREMY BLAKESLEE

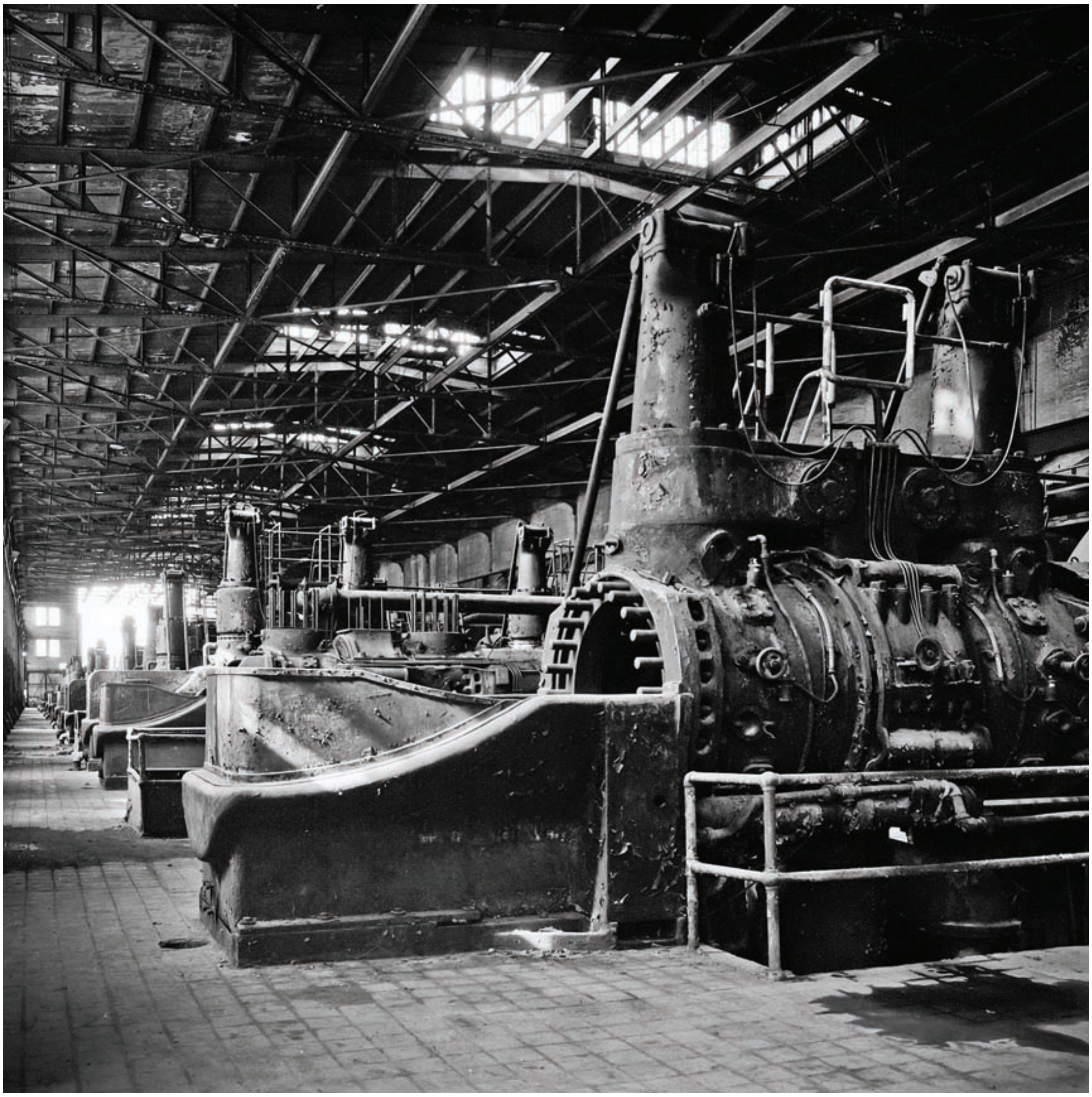


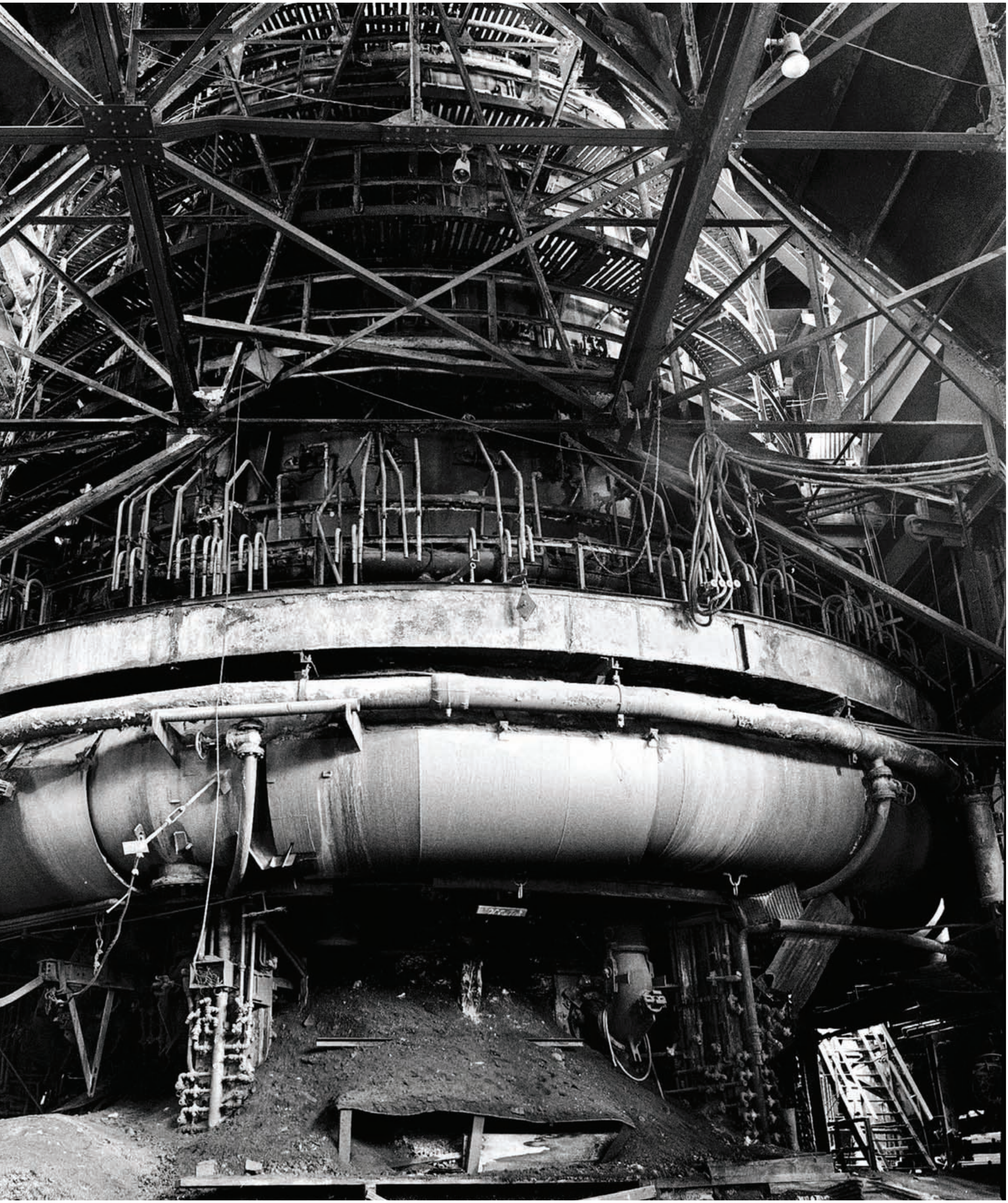


In the heart of the Lehigh plant, in Bethlehem, Pennsylvania, five blast furnaces (left) smelted iron from ore in the first phase of the steelmaking process.

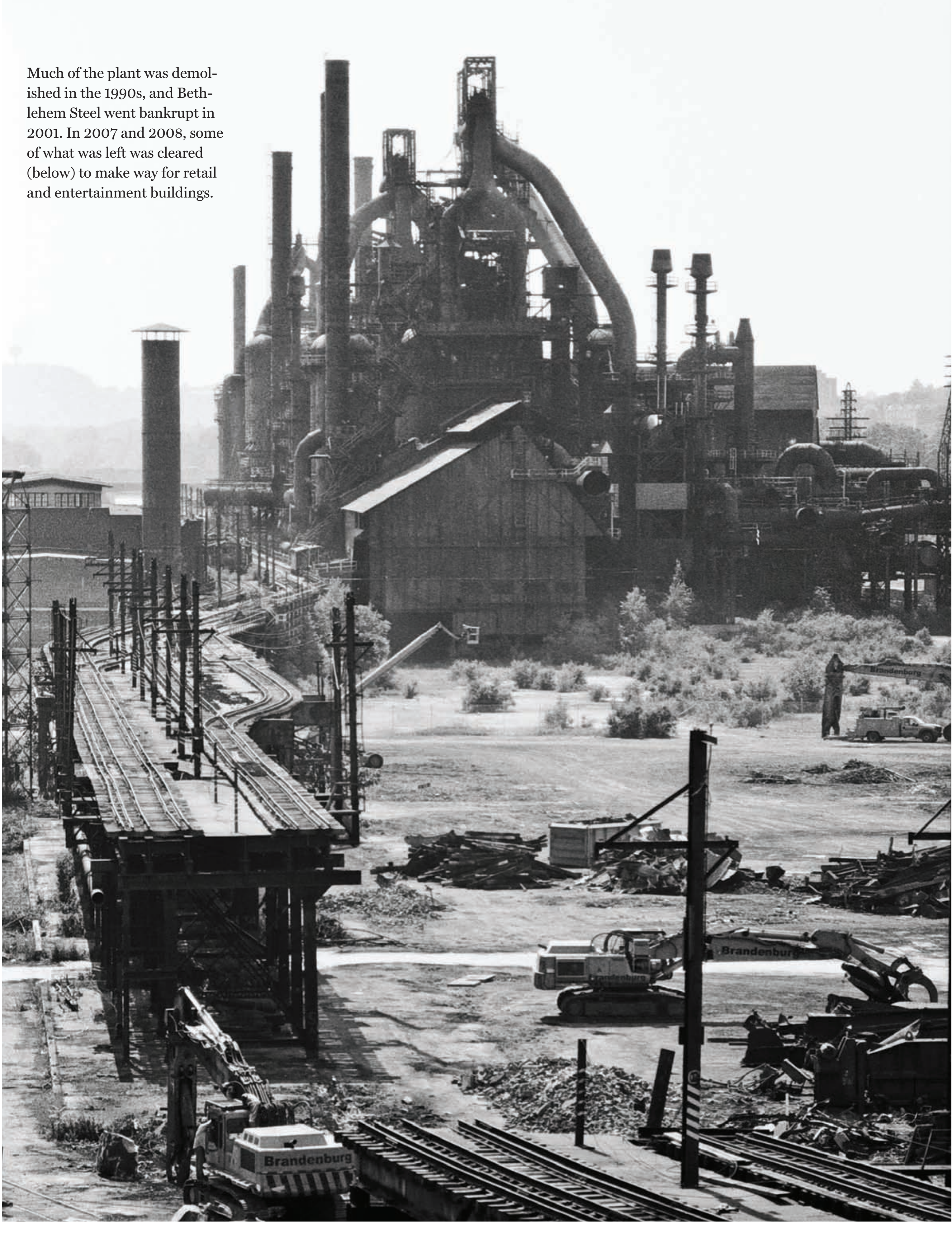
The machine shop at left was thought to be the world's largest building of its kind at the time of its completion in 1891. In the welfare room (above), workers would place their valuables and street clothes in a basket for safekeeping during the work day.

Internal-combustion engines (below) pumped air into the blast furnaces to get them hot enough to smelt iron from ore. Blast Furnace A (right), built in 1915, is the only remaining furnace of its kind in the United States.





Much of the plant was demolished in the 1990s, and Bethlehem Steel went bankrupt in 2001. In 2007 and 2008, some of what was left was cleared (below) to make way for retail and entertainment buildings.



One of the largest new residents of the Bethlehem site is the Sands Casino Resort. A major challenge in building the $743 million facility was finding enough steel.

MANUFACTURING

Can We Build Tomorrow's Breakthroughs?

Manufacturing in the United States is in trouble. That's bad news not just for the country's economy but for the future of innovation.

By DAVID ROTMAN

In a hangarlike building where General Electric once assembled steam turbines, a $100 million battery manufacturing facility is being constructed to make products using a chemistry never before commercialized on such a large scale. The sodium–metal halide batteries it will produce have been tested and optimized over the last few years by a team of materials scientists and engineers at GE's sprawling research center just a few miles away. Now some of the same researchers are responsible for reproducing those results in a production facility large enough to hold three and a half football fields.

The engineers have moved from the bucolic research center, which sits on a hill overlooking the Mohawk River, down to the manufacturing site, which abuts the river at the edge of Schenectady, New York, a working-class town known in its heyday as Electric City. There, they supervise the installation and testing of robotics, high-temperature kilns, and analytic equipment that will monitor the production process. The new batteries use an advanced ceramic as an electrolyte inside a sealed metal case containing nickel chloride and sodium;

Photographs by IAN ALLEN

POWERING UP GE's new facility will make an innovative type of battery for data centers and backup power.


DANGER
HIGH VOLTAGE

the technology promises to store three times as much energy as the lead-acid batteries used in data centers, in heavy-duty electric vehicles, and for backup power. But almost anything can go wrong. If, say, the particles that make up the ceramic are uneven in size or haven't been properly dried, battery performance could fall short. That means the conditions in the huge factory must be tightly controlled, and multi-ton devices must be able to match the exactness of lab equipment. "It's not for the weak of heart," says Michael Idelchik, GE's vice president of advanced technologies.

The GE plant is one of a number of facilities around the country producing new technologies for rapidly growing markets in advanced batteries, electric vehicles, and solar power—but those efforts cannot counter the reality that the U.S. manufacturing sector is in trouble. After decades of outsourcing production in an effort to lower costs, many large companies have lost the expertise for the complex engineering and design tasks necessary to scale up and produce today's most innovative new technologies, not to mention the appetite for the risks involved.

If you believe Thomas Friedman's assertion that "the world is flat," and that moving manufacturing to places where production is cheap makes companies more competitive, such a shift might not matter beyond its implications for the U.S. economy and its workers. But the United States remains the world's most prolific source of new technologies, particularly materials-based ones, and evidence is growing that its diminished manufacturing capabilities could severely cripple global innovation. There are ample reasons to believe that the model of the U.S. computer industry—which has successfully outsourced much of its production in the last few decades and made design, not manufacturing, its priority—will not work effectively for companies trying to commercialize innovations in energy, advanced materials, and other emerging sectors.

Academic researchers have begun documenting the complex connections between innovation and manufacturing with an eye to clarifying how the loss of U.S. manufacturing could affect the emergence of new technologies. Willy Shih, a professor of management at Harvard Business School, has created a list of basic technologies in which the United States has squandered its lead in manufacturing in recent years. They include crystalline silicon wafers, LCDs, power semiconductors for solar cells, and many types of advanced batteries. And he has detailed how losing the "industrial commons"—the research know-how, engineering skills, and manufacturing expertise needed to make a specific technology—can often mean losing the knowledge and incentives to create advances in related technologies. For example, as silicon semiconductor production and associated supply chains have shifted to Asia, the development of new silicon-based solar cells has been hampered in the United States.

It turns out it's not necessarily true that innovative technologies will simply be manufactured elsewhere if it doesn't happen in the United States. According to research by Erica Fuchs, an assistant professor at Carnegie Mellon University, the development of integrated photonics, in which lasers and modulators are squeezed onto a single chip, has been largely abandoned by optoelectronic manufacturers as they have moved production away from the United States. Many telecom firms were forced to seek lower-cost production in East Asia after the industry's collapse in the early 2000s, and differences in manufacturing practices meant that producing integrated photonic chips was not economically viable in those countries. Thus a technology that once appeared to be just a few years away from revolutionizing computers and even biosensors was forsaken. Economists might argue that we don't care where something is produced, says Fuchs, but location can profoundly affect "the products that you choose to make and the technology trajectory itself."

IN STEP A key part of GE's battery production process is the fabrication of ceramic tubes, which act as an electrolyte. Above is the "calciner," critical in fabricating powders for the ceramic. At left, the white tubes move down an assembly line, where they will be sealed to complete the ceramic assembly that goes into the battery cell.

For many people in industry, the connections between innovation and manufacturing are a given—and a reason to worry. "We have learned that without a foothold in manufacturing, the ability to innovate is significantly compromised," says GE's Idelchik. The problem with outsourcing production is not just that you eventually lose your engineering expertise but that "businesses become dependent on someone else's innovation for next-generation products." One repercussion, he says, is that researchers and engineers lose their understanding of the manufacturing process and what it can do: "You can design anything you want, but if no one can manufacture it, who cares?"

After decades as the world's largest manufacturer, the United States now makes, according to some recent estimates, 19.4 percent of the world's manufactured goods—second to China, which makes 19.8 percent. Even in high-tech products, the United States now imports more than it makes. Those statistics have implications for employment, national competitiveness, and even the politics and social structure of the country. But equally worrisome, especially over the long term, is what the declining ability of the United States to make stuff implies for the next generation of technology.

The United States remains the world's most prolific source of new technologies, particularly materials-based ones, and evidence is growing that its diminished manufacturing capabilities could severely cripple global innovation.

Can the United States regain its ability to take on high-risk manufacturing? To ask the same question in a different way, are many of today's most promising innovations in danger of suffering the same fate as integrated photonic chips?

ELECTRIC MOTOR CITY

The city of Detroit, for decades the center of U.S. auto manufacturing, likes to tout its efforts at urban renewal. A modern baseball stadium sits at the edge of downtown; a bustling theater district is nearby. Yet empty and gutted skyscrapers are within walking distance of the shiny glass towers of General Motors' headquarters and the new condos that rise above the city's riverfront. And on the outskirts of the city, in areas bisected by highways with names such as Chrysler Freeway and Edsel Ford Freeway, the devastation is even more evident in the seemingly endless stretches of abandoned industrial buildings. Some 22 percent of the jobs in Michigan are still tied to automotive manufacturing, and a decade of bankruptcies and plunging sales among Detroit automakers has left the region reeling. Nearly a half million jobs have been lost in southeast Michigan since 2000.

Amid the ruins, however, the GM Detroit Hamtramck assembly plant is an oasis of order and activity. Though its parking lot is less than half full on a day in early fall, the massive plant, built in the mid-1980s to make Cadillacs and Buicks, embodies Detroit's attempt to reinvent itself. A field of solar panels has been installed in front of it; at the edge of the visitors' parking lot is a row of carports equipped with electrical outlets.

Inside the plant, Cadillacs and Buicks have been replaced on the assembly line by the Chevrolet Volt, GM's recently introduced electric car, and its European counterpart, the Opel Ampera. The electric vehicles fill roughly every other available space on the production line, but GM hopes to ramp up production to 60,000 electric cars by next year. Like any modern auto manufacturing plant, the Detroit Hamtramck facility is a whirl of robotics and large parts moving deliberately along assembly lines that merge at critical points; at one of those intersections, the painted steel frame is slowly dropped down on the chassis and engine. Automated pneumatic wrenches puncture the relative quiet as they apply precise torque to bolt the pieces together.

Near the center of all the activity, sitting by themselves, are the T-shaped lithium-ion batteries that are the heart of the new car and a source of economic hope for much of Michigan. The 435-pound battery pack is a vast improvement over the hulking, 1,100-pound lead-acid batteries used in the ill-fated first generation of electric cars that GM made in the 1990s. The smaller, lighter new batteries are far easier to accommodate in a compact car like the Volt, and the new chemistry improves the vehicle's performance.

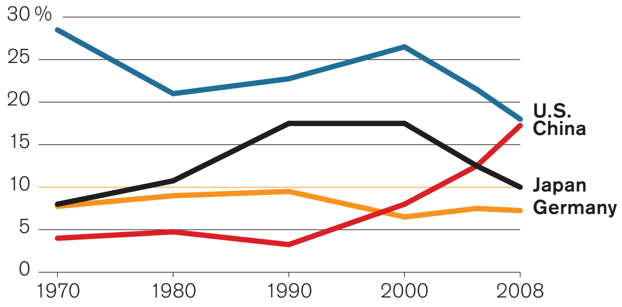
Each battery pack contains some 288 cells, each of which contains a series of precisely matched thin sheets of anodes and cathodes. If GM makes 60,000 Volts next year, those cars would easily consume the output of several huge battery manufacturing plants. But if the electric-car market suddenly takes off—say, because of cheaper or more efficient batteries—the need could be far greater. It's been estimated that if electric cars accounted for a tenth of U.S. auto sales, 43 large battery factories would be required to supply the automakers.

The potential appetite for batteries among GM and other automakers has led to the construction of at least half a dozen manufacturing and assembly plants in a 200-mile radius around Detroit. Spurred in part by the Obama administration's $2.4 billion in funding for advanced-battery production and electric vehicles, this

MAKING TROUBLE

The lead of the United States as the clear front-runner in manufacturing output has been challenged by China in recent years.

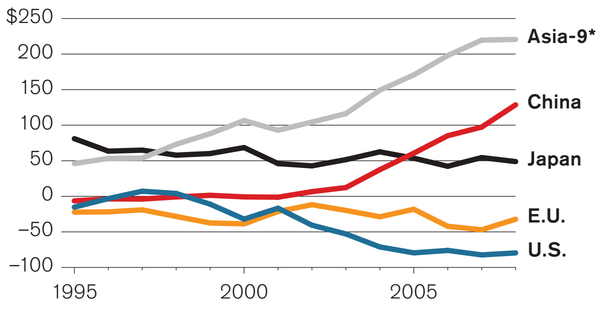
World manufacturing output (percent share, 1970–2008)



Sources: United Nations Conference on Trade and Development, ITIF

Even in high-tech products, the United States now imports more than it exports.

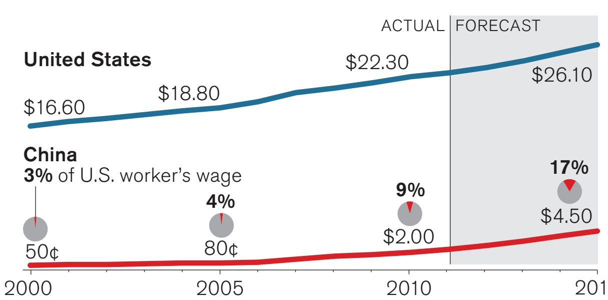
Trade balance in high-technology goods (in billions, 1995–2008)



Sources: IHS Global Insight, World Trade Service Database
**Asia-9 refers to India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, and Vietnam.*

Differences in labor costs between China and the U.S. are shrinking, forcing some to rethink where to locate production.

Factory-worker wages (dollars per hour)



Sources: Economist Intelligence Unit; U.S. Bureau of Labor Statistics; selected company data; BCG analysis

TOMMY McCALL

development presents a vision of what a recovery in the region's manufacturing base might look like. It also presents a snapshot of the huge challenge involved in creating such an infrastructure.

About 125 miles north of the Detroit Hamtramck assembly plant is one of the largest of the new battery facilities. Dow Kokam, a joint venture of Dow Chemical, TK Advanced Battery, and the French firm Groupe Industriel Marcel Dassault, is building a $322 million factory in Midland, Michigan, that will be able to make enough lithium-ion battery cells for some 30,000 electric cars. Though construction is ongoing and much of the equipment is still being installed, a quick tour gives a sense of the operation's size and complexity. In one large high-ceilinged room are a vast number of automated racks where each battery cell will be "formed," a critical operation in which the battery is charged and discharged to precisely set the chemistry.

It's this kind of scale and attention to detail that attract the interest of companies like Dow, the world's second-largest chemical producer. The plant sits just outside the boundaries of Dow's Michigan chemical operations, a small city of low-rise production buildings connected by a maze of crisscrossing overhead pipes. It's a sprawling testimony to the connections between various ingredients and feedstocks used in making industrial products, and to the efficiencies of scale often required in manufacturing.

The supply chain for lithium-ion battery manufacturing starts deep within the chemical complex. Somewhere down one of the streets that run through the plant is a nondescript building where workers once made chemicals used in plastics. Now Dow is turning it into a production facility for the cathode and anode materials needed in lithium-ion batteries. Anyone who enters must don a white coat, wrap shoes in paper coverings, and submit to an air-spray shower designed to remove stray dust and particles. Inside, the powders for the cathodes and anodes are processed in large containers designed to minimize contamination. The materials will be shipped to one of the battery plants being built; though the nearby Dow Kokam plant is not obligated to buy the anodes and cathodes from its parent company, it would be a natural fit.

Like GE's Idelchik, Dow's chief technology officer, William Banholzer, acknowledges the risks of scaling up new technologies. But he says Dow's size and deep pockets allow it to take risks that would be difficult for small startups, and its extensive infrastructure allows it to efficiently integrate the various aspects of the manufacturing process. Dow's size also allowed it to hedge its bets on batteries by entering other new energy markets. On the opposite side of the vast manufacturing complex from the Dow Kokam plant, it is building a solar manufacturing facility, which will make roofing shingles that incorporate thin-film photovoltaics. "The scale of energy is so big it's very tough to say energy is going to get solved by small companies," says Banholzer. It's not

POWER HUNGRY The GE battery factory covers a space the size of three and a half football fields and includes such energy-intensive equipment as large kilns. The electrical equipment at right supplies the immense factory with power.

until you've actually begun manufacturing that you "get a look at your true costs and warts," he says. In energy businesses where a demonstration plant might cost $500 million, "the venture-capital model breaks down," he adds. "The big question is: can small companies ever compete with big companies in this area?"

SURVIVAL INSTINCTS

It is a question that gets at one of the key challenges involved in reviving the manufacturing sector. Banholzer is surely correct that startups cannot compete with the production capacity of a Dow or GE. But it also true that small companies are working on some of our most promising technologies, especially at the intersection of new materials and energy. If those technologies can be produced economically, they could greatly expand existing markets. The challenge for the startups, then, is to figure out a way to make their technologies using current manufacturing know-how while developing products that are radical enough to disrupt established technologies.

Ann Marie Sastry clearly thinks her startup can do just that. Housed in a small industrial park in Ann Arbor, Michigan, Sakti3 is working on a next-generation technology for solid-state batteries *(see TR10, May/June 2011)*. The fabrication area in the back of the offices is strictly off limits to visitors, as are cameras and questions during a quick tour of the testing and design areas; CEO Sastry will reveal few details about the technology except to say that the battery has no liquid electrolytes and the company is using manufacturing equipment that was once employed to make potato-chip bags. But she is more forthcoming in explaining how the startup can thrive in the highly competitive advanced-battery sector.

The strategy begins with the recognition that any new technology must promise advantages far beyond what is possible with existing products. "If you start with the current [lithium-ion] technology," she says, "you may get five or 10 or 20 points' worth of performance by tweaking that process, but you have to accept that you're never going to get anything transformative." But doubling the energy density of batteries could have an enormous impact in powering communication devices, she says, especially in areas with little access to electricity for frequent charging. Transportation could be affected even more profoundly. New batteries with greater energy density and significantly lower cost could raise demand for electric vehicles to a whole new level, she says.

So she and her colleagues "started with the periodic table" to invent a new battery. From the first, the company knew the technology had to scale. "We didn't take a clean sheet of paper to manufacturing," she says. "We started by an analysis of manufacturing approaches that had been and could be scaled."

Looking to the periodic table for materials that might overturn current technology is a frequent strategy these days for early-stage energy startups. Gerbrand Ceder, a materials scientist at MIT, initiated a "materials genome project" several years ago that uses computers to analyze and predict the properties of materials "across the known chemical universe" and hopes to create an open database of the information. (After the White House announced its Materials Genome Initiative, he agreed to rename his effort the Materials Project to avoid any confusion.) A major goal is to more efficiently identify materials that are suitable for manufacturing.

Ceder has systematically analyzed various compounds for their potential as battery materials. Using the computational tools developed by his materials genome project, Pellion, a startup in Cambridge, Massachusetts, that he cofounded in 2009, has identified new cathodes for a magnesium-based battery. If it works, Ceder says, the batteries could have double or triple the energy density of today's lithium-ion batteries. Equally important, he says, they could "feed into the existing lithium-ion battery manufacturing." And

that's critical, he says, because "if you have to invent a new material that can replace the existing one, it might take five to 10 years, but if you also have to invent a new design, it can take 10 to 20 years."

Other promising early-stage energy startups are based on efforts to circumvent well-known manufacturing limitations. For example, Alta Devices, a company in Santa Clara, California, whose founders include leading researchers from Caltech and the University of California, Berkeley, is developing a way to make photovoltaic cells using films of gallium arsenide that are only a micrometer thick. Gallium arsenide, which is widely used as an ingredient in lasers and other photonic devices, has great optical properties but is too expensive for most solar cells. The new technology, however, uses so little of the material that its price is no longer prohibitive. Alta Devices has spent the last several years perfecting the production process; it has begun a pilot line to make the photovoltaic materials next year and hopes to start commercial production in 2013.

As the risks and cost of scaling up energy technologies grow increasingly evident, it's becoming common for startups to consider the practicalities of manufacturing when they conceive their innovations. But how does a tiny company, even with a radically different material, hope to succeed in highly competitive solar and battery markets that require huge capital investments? Partnering with a large company is an obvious strategy. Alta Devices, for example, is working with Dow on next-generation materials for the chemical company's solar shingles; GM is an investor in Sakti3. Still, the energy startups face the daunting truth that scaling up innovations into successful manufacturing operations can take hundreds of millions of dollars.

There is, however, at least one recent example of success.

LEARNING CURVE

When Yet-Ming Chiang cofounded A123 Systems in 2001 on the basis of his MIT research on battery materials, there was no advanced-battery manufacturing in the United States. Although much of the scientific work that led to the invention of lithium-ion batteries had been done in this country, including advances achieved at the University of Texas, it was Sony that commercialized the batteries in 1991. Subsequently, manufacturers in Korea and China made significant investments in the technology. With four times the energy capacity of nickel-cadmium batteries and

twice that of newer nickel–metal hydride ones, lithium-ion batteries became the dominant technology in consumer devices, making today's small, powerful cell phones and laptops possible.

Meanwhile, the two major U.S. battery producers, Duracell and Eveready (now called Energizer), tried to develop their own lithium-ion products during the 1990s. Eveready got as far as building a factory in Gainesville, Florida, but even as the plant prepared for commercial production, the price of lithium-ion batteries dropped and the company decided it was cheaper to buy cells from Japanese producers than to make its own. It exited the lithium-ion battery business, and Duracell soon followed.

So Chiang and his colleagues at A123 built a manufacturing plant in Changzhou, China *(see "An Electrifying Startup," May/June 2008)*. The move was meant not to outsource production, says Chiang, but to acquire the needed manufacturing know-how. Subsequently, A123 bought a South Korean manufacturer as a way to begin developing the expertise it needed to make the flat cells required for electric-car batteries. When A123 decided it needed to be closer to its potential automotive customers in Detroit, it cloned the Korean plant in Livonia, Michigan, and the Chinese factory a few miles away in Romulus, aided by a $249 million grant from the federal government. As a result of this strategy, A123 was able to become a major manufacturer in a remarkably short time, building the Livonia plant in just over a year and the Romulus plant in nine months.

The company soon became one of the nation's highest-profile energy startups—and one of the few that have scaled up their technology, building what it claimed in 2010 was the "largest lithium-ion automotive battery plant in North America." In 2009 it went public, raising around $400 million. But unfortunately for those hoping to emulate such success, the political and financial circumstances that allowed A123 to garner nearly $1 billion in private and public investments are long gone.

One of the lessons from A123 is "exactly how much it cost" to become successful, Chiang says. "And one wonders how often that can be replicated. In the current climate, one wonders whether there is a will to do this over and over again." In the biotech industry, the path to commercialization has become clear over the years—partnering with large pharmaceutical companies, meeting expected milestones, and undergoing the regulatory approval process required for new products. But it's not so simple for energy startups, says Chiang, whose latest startup, 24M, is hoping to develop a radically new battery technology. Those small companies developing new energy technologies, he says, "still have to figure it out."

TEAM SPORTS

These days, Evergreen Solar's three-year-old manufacturing plant in Marlborough, Massachusetts, sits empty with a large "For Lease" sign in front. The bankruptcy of Evergreen in August, and of Solyndra a month later, produced much hand-wringing over the future of solar power. In particular, the collapse of Solyndra, a Silicon Valley–based manufacturer that had received a $535 million loan guarantee from the federal government, has led to criticism of the role the government has played in supporting renewable energy and, in particular, its poor record in "picking winners."

The government does have a record of backing some notorious energy failures. And scaling up new technologies is, of course, risky. But such criticisms have overshadowed the arguably more interesting lessons that can be gleaned from the bankruptcies: in many ways, the companies' failures of both strategy and execution were manufacturing failures. Their business models depended on using radically new technologies to bring down the cost of making solar panels, ignoring the truism that new technologies are initially almost never cheaper than well-optimized existing processes. And neither company had products innovative enough to induce most customers to pay a premium price. Evergreen and Solyndra faced many unexpected market changes—among them a sudden drop in silicon prices and the overproduction of solar panels—but the ability of competing companies to continue lowering their manufacturing costs for more conventional solar panels shouldn't have been a surprise *(see "The Chinese Solar Machine," p. 46)*.

The industrial commons are fragile, and their survival will depend both on markets and on government policies. The birth of advanced-battery manufacturing in Michigan is largely a result of $2.4 billion in support from the Obama administration.

There are other manufacturing lessons to be learned from the collapses of these two businesses. Evergreen's innovation revolved around a single step in the production process—a way to make silicon wafers more cheaply. Yet the company made and sold complete solar panels—and they were a different size from the industry standard, forcing its customers into the undesirable position of making a long-term commitment to a specific technology.

Likewise, Solyndra (one of *TR*'s 50 most innovative companies in 2010) made a series of manufacturing missteps. In a filing with government regulators in December 2009, the company acknowl-

edged that "our custom-built equipment may take longer and cost more to engineer and build than expected and may never operate as required to meet our production plans." Such words of caution are often boilerplate in these filings, but in this case they were prescient. In particular, Solyndra attempted to build out its manufacturing capacity at a rapid pace, planning a second production plant even as it was still expanding the first one—and losing vast amounts of money because of its relatively high costs. In retrospect, it is obvious that both companies expanded manufacturing far too fast, with far too little understanding of their unique production processes, their competition, or their customers' requirements.

A way to avoid such mistakes is to increase collaboration among companies developing new technologies. The outskirts of Albany will never be confused with Silicon Valley, but the names of the companies at the College of Nanoscale Science and Engineering there are familiar to anyone in the semiconductor industry: Intel, IBM, TSMC, Applied Materials, and Tokyo Electron. The idea is that the shared facilities provide an opportunity for chip makers, equipment suppliers, and engineering companies to develop and evaluate their products. Last year Sematech, the U.S. consortium of semiconductor companies, moved its operations to the $12 billion complex. Its newest initiative: to help revive the U.S. solar industry the same way it helped the semiconductor industry regain its footing in the 1980s and 1990s.

One of the lessons of the Solyndra failure is that it involved "betting on a very risky technology" and spending hundreds of millions on unproven production processes, says Pradeep Haldar, who leads the new Photovoltaic Manufacturing Consortium in Albany, a partnership between Sematech and CNSE. In contrast, he says, manufacturers of thin-film solar cells can use the existing infrastructure at the Albany facility to get "a reality check," including reactions from materials suppliers and potential customers.

This collaborative approach is attractive even for large manufacturers such as GE. "Innovation is a team sport," says Idelchik, but too often in the United States "we're trying to do it in a vacuum." Opportunities like those offered at the Albany nanotech center are particularly important, he believes, because manufacturers are in a period of transition. The worldwide recession that began in 2008 left companies with vast amounts of overcapacity, but costs for materials and labor have continued to rise along with the standard of living in countries such as China and India. This means it's no longer effective to try to squeeze cost out of manufacturing by, for example, chasing lower-priced labor. To stay competitive, Idelchik says, companies need to move to "high-risk, high-payoff" manufacturing of advanced products and materials. However, he adds, such high-risk manufacturing requires an "ecosystem" of suppliers, equipment makers, and customers.

That ecosystem is essentially what Harvard's Willy Shih calls the "industrial commons." However it's described, it is what the United States has lost in LCDs and integrated photonics, has nearly lost in advanced batteries, and is rapidly losing in silicon solar panels. It is what A123 and Dow are attempting to help rebuild for advanced batteries in Michigan, what Sematech hopes to initiate for thin-film solar panels, and what startups like Pellion, 24M, and Alta Devices all hope they can leverage—and then eventually disrupt.

Whether such startups survive will depend, ironically, very much on whether the markets they ultimately hope to replace are robust and growing. Yet the industrial commons are fragile, and their survival will depend both on markets and on government policies. The birth of advanced-battery manufacturing in Michigan is largely a result of support from the Obama administration. Whether it thrives will depend on how many electric cars GM and others are able to sell and whether the government continues to provide incentives for the fledgling industry, including funding for research. In the longer term, its health may very well depend on how well it is able to adopt truly innovative new technologies from the early-stage startups. The consequences will be felt deeply. As Shih has demonstrated, the United States has lost key manufacturing sectors and related innovation skills multiple times. And his list of today's at-risk technologies is long. If advanced batteries, solar technologies, and manufacturing of advanced materials become yet more casualties, it will surely damage the ability to invent future technologies.

These days Yet-Ming Chiang is spending at least part of his hectic schedule among the cramped cubicles of 24M, a five-minute bike ride from his MIT labs. About three years ago, while working at A123 on a sabbatical from MIT, Chiang began thinking about what the next generation of battery technology might look like. Much of the expense of manufacturing lithium-ion batteries is due to various non-active components and the multistep process of layering the electrodes and cathodes. The actual energy-storing parts—the electrodes and electrolyte—account for roughly a fifth of the total cost. What if, he wondered, you could design a battery that got rid of the non-energy-storing ingredients and the expensive cell and module assembly? The result is the flow battery that 24M is developing, in which the electrodes circulate in a semisolid form. A potential benefit of this design is that manufacturing it could be much less capital-intensive. What's more, says Chiang, it is designed to work with the existing supply chain and manufacturing infrastructure for lithium-ion batteries.

Chiang says his experience with A123 was critical in coming up with the new battery design. "The best way to do battery research is having started a battery company," he says. "Being close to the manufacturing, you recognize what can have an impact. It is the argument for why manufacturing is so important in these developing areas." tr

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DAVID ROTMAN IS *TECHNOLOGY REVIEW*'S EDITOR.

The Chinese Solar Machine

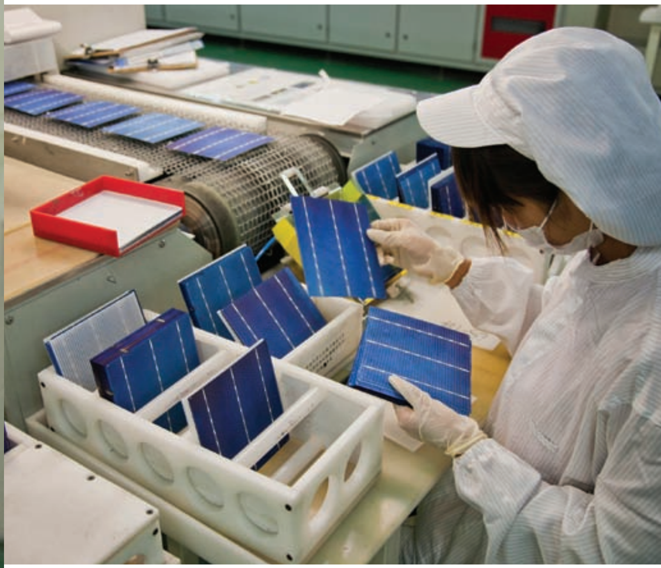
Chinese manufacturers have dominated the international market for conventional solar panels by building bigger factories faster. Now they will need to innovate to maintain their lead.

By KEVIN BULLIS

Ten years ago, solar panels were made mostly in the United States, Germany, and Japan. Chinese manufacturers made almost none. But by 2006, the Chinese company Suntech Power had the capacity to make over a million silicon-based solar panels a year and was already the world's third-largest producer. Today Chinese manufacturers make about 50 million solar panels a year—over half the world's supply in 2010—and include four of the world's top five solar-panel manufacturers. What makes this particularly impressive is that the industry elsewhere has been doubling in size every two years, and Chinese manufacturers have done even better, doubling their production roughly every year.

This dominance isn't due to cheap labor in Chinese factories: making solar cells requires such expensive equipment and materials that labor contributes just a small fraction of the overall cost. Nor is it because the Chinese companies have introduced cells that last longer or produce more power: by and large, they make the same type of silicon-based solar panels as many of their competitors around the world, using the same equipment. They have

Photographs by KEVIN LEE



CELL MAKERS At a factory in Wuxi, China, a machine that uses a novel process developed by Suntech Power etches the surface of crystalline silicon wafers for solar cells (far left). The process helps the cells absorb more light. At center, a worker inspects the wafers after they've been etched. Above, a worker sorts solar cells by appearance as they emerge from a machine that produces electrical contacts.

succeeded in large part because it's faster and cheaper for them to build factories, thanks to inexpensive, efficient construction crews and China's streamlined permitting process. The new factories have the latest, most efficient equipment, which helps cut costs. So do the efficiencies that come with size. As a result, Chinese manufacturers have been able to undercut other makers of silicon solar panels and dash the hopes of many upstarts hoping to introduce novel technology.

But the solar market is rapidly evolving, and technological innovations are becoming increasingly essential. Though demand for solar power continues to grow around the world, the market is flooded with photovoltaic panels: worldwide production capacity more than doubled from 2009 to 2010 and continued to increase in 2011. The overcapacity was so great that last fall, Chinese manufacturers had trouble selling solar panels for more than it cost to make them. In such a market, the way to differentiate your product—and charge enough to stay afloat—is to make it better than your competitors'.

For solar manufacturers today, that means inventing cells that are more efficient at converting light to electricity. As the price of solar panels has fallen, installation costs have come to account for a greater percentage of solar power's cost. Customers want panels that are more powerful, so that they can install fewer of them. From now on, the best way for Chinese manufacturers to lower the cost per watt of solar power may not be by lowering manufacturing costs but, instead, by increasing the number of watts each panel generates. "The game is now changing," says Mark Pinto, executive vice president of energy and environment solutions at Applied Materials in Santa Clara, California, the world's largest supplier of solar manufacturing equipment. "Before, it was all about scale. Now it is about conversion efficiency while keeping the cost down."

This might sound like bad news for Chinese manufacturers that have focused on scaling up standard technology. But their experience in building conventional solar panels could help them implement new designs that significantly boost the performance of silicon solar cells. Over the years, these manufacturers have

SOLAR ILLUMINATION Workers solder electrical connections to solar cells in anticipation of linking them together to form solar panels (left). After the cells are wired together in strings, they're aligned on top of a light box. The front and back of the cells are covered with an encapsulating material, and then they're fed into a laminator to seal them in place (center). As part of quality control, a worker prepares solar panels for a test that measures their degradation under bright ultraviolet light (right).

lowered costs in part by developing better ways to manufacture the cells. That's given them an understanding of what works and what doesn't on the factory floor. They also have the capital and the engineers to help them translate newer technologies into mass production. They might not have initially set out to commercialize those technologies, but now, having mastered the market for conventional solar panels, they're poised to do just that.

KEEPING PACE

In 2010, when the U.S. secretary of energy, Steven Chu, gave a speech to the National Press Club laying out his case that the United States was falling behind in advanced manufacturing, Suntech Power was his Exhibit A. He had toured its factory, and he was impressed by what he'd seen. "It's a high-tech, automated factory," he said. "It's not succeeding because of cheap labor." Not only that, he noted, but Suntech had developed a type of solar cell with world-record efficiencies.

Chu's assessment might have surprised some observers, but Suntech's record-setting solar cells *are* impressive. The technology that goes into them takes advantage of changes in both design and manufacturing technique. The conductive metal lines that collect electric charge from the silicon aren't created with screen-printing methods, as is standard. Instead, Suntech uses a proprietary process to deposit much thinner, more closely spaced lines that are more efficient at extracting electricity from the cells. The changes have allowed the company to reach efficiency levels and cost reductions that an industry road map released in 2011 had set as targets for 2020. "When you put all those things together, we are not only doing better than what people are doing now," says Stuart Wenham, the chief technology officer at Suntech. "We are also doing better than what they think they could be doing in 10 years."

So far, Suntech has made relatively few solar panels based on the new technology. Instead, it has focused its resources on tweaking manufacturing processes to decrease the cost of making conventional silicon solar panels. But that could soon change. This year Suntech has started to increase production of the new cells, and now it can make enough of them annually to generate 500 megawatts of power—roughly 2.5 million solar panels. That achievement owes much to the company's success as a producer of the conventional products.

The technology behind the new cells was developed in the 1990s at the University of New South Wales, Australia, but the techniques used in the lab were too expensive for commercial production. It was a "horribly sophisticated process" including photolithography, vacuum deposition of "quite exotic metals," and "all sorts of chemical processes," says Wenham, who is also head of the photovoltaics research program at UNSW and was formerly a professor of Suntech's CEO and founder, Zhengrong Shi. According to Wenham, the technology remained a lab curiosity for decades until Suntech's researchers figured out how to adapt it to an assembly line. "They came up with a simple, low-cost way to replace all of that while achieving the same results," he says. The new technology could increase the power output of a standard-sized solar panel from 205 watts to 220 watts or more—and the cells costs less to produce than conventional ones.

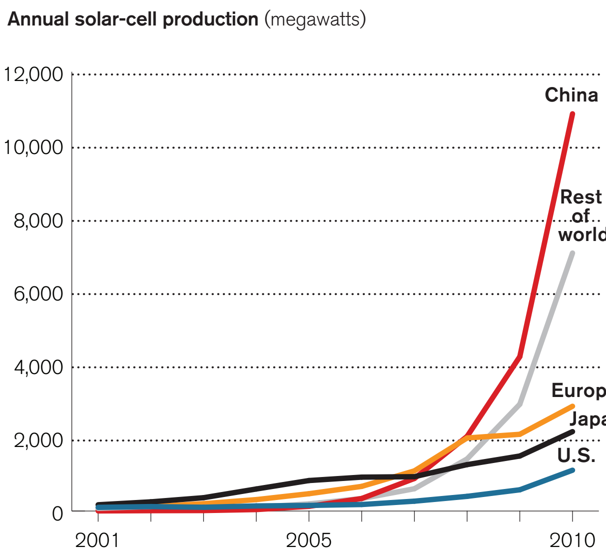
Individual parts of the technology were quickly successful. Suntech introduced these into its standard manufacturing lines, with

an eye to keeping just ahead of its competitors in terms of cost and efficiency. Scaling up the complete process, however, was a challenge. A pilot manufacturing line was up and running in 2009, but the company had to develop and implement new equipment to get yields and production rates to the point that the process was economical. Here Suntech's position as a market leader with experience in developing new manufacturing equipment proved critical. Not only did the company have the expertise it needed to improve the process; it also had the funds to keep working on the technology for years without its bringing in significant revenue.

Suntech isn't the only Chinese solar manufacturer to identify promising new technology and find ways to produce it at a large scale. Last September, Yingli Green Energy, based in Baoding, announced that a partnership with a Dutch research center, ECN, had yielded solar panels that could convert 17.6 percent of the energy in sunlight into electricity; the average is just over 14 percent. "ECN made the technology available to anyone in the world who wanted it," Wenham says. "Yet it's only been Yingli that's taken that technology and worked out how to make it in large-scale production, at low cost."

FAR AHEAD

China's production of solar cells is far outpacing everyone else's.



Source: GTM Research

MATERIAL ADVANTAGE

Even now that Chinese solar manufacturers are shifting focus from production to innovation, there may be limits to what they can do with their chosen material, crystalline silicon. This material is attractive because the industry knows how to work with it, thanks in part to decades of research in silicon microchips. But compared with some other semiconductors, it's lousy at absorbing sunlight. Some alternatives, like gallium arsenide, can be made into films of material that can generate as much electricity as a typical silicon cell but are just a hundredth as thick, potentially reducing material costs. Such thin films can also be flexible: they could be rolled up, reducing packaging and shipping costs, and they could be built into roofing shingles to reduce installation costs.

Yet despite their potential advantages, it has been difficult for thin-film solar cells to compete with the ever decreasing costs and improving efficiency of crystalline silicon ones. One company, Arizona-based First Solar, has succeeded in developing low-cost manufacturing techniques for thin-film solar panels, but these methods use a material—cadmium telluride—that results in panels less efficient than silicon ones. Other companies have tried to compete with silicon by using higher-efficiency thin-film panels of copper indium gallium selenide. Some of them, however, have had to declare bankruptcy and close their factories after failing to lower manufacturing costs fast enough.

Despite these struggles, Wenham believes that thin-film technology will eventually challenge conventional solar panels. If that's true, Chinese makers of crystalline silicon solar cells may not dominate the market forever. But the strategy of first scaling up conventional technology and then introducing innovative designs to keep lowering the cost per watt of solar power has put them in a good position to maintain their lead for years. In the meantime, some, like Suntech, are working to produce thin-film panels of their own. When thin films do replace crystalline silicon, it could be Chinese manufacturers that make them. tr

KEVIN BULLIS IS *TECHNOLOGY REVIEW*'S SENIOR EDITOR FOR ENERGY.

Layer by Layer

With 3-D printing, manufacturers can make existing products more efficiently—and create ones that weren't possible before.

By DAVID H. FREEDMAN

The parts in jet engines have to withstand staggering forces and temperatures, and they have to be as light as possible to save on fuel. That means it's complex and costly to make them: technicians at General Electric weld together as many as 20 separate pieces of metal to achieve a shape that efficiently mixes fuel and air in a fuel injector. But for a new engine coming out next year, GE thinks it has a better way to make fuel injectors: by printing them.

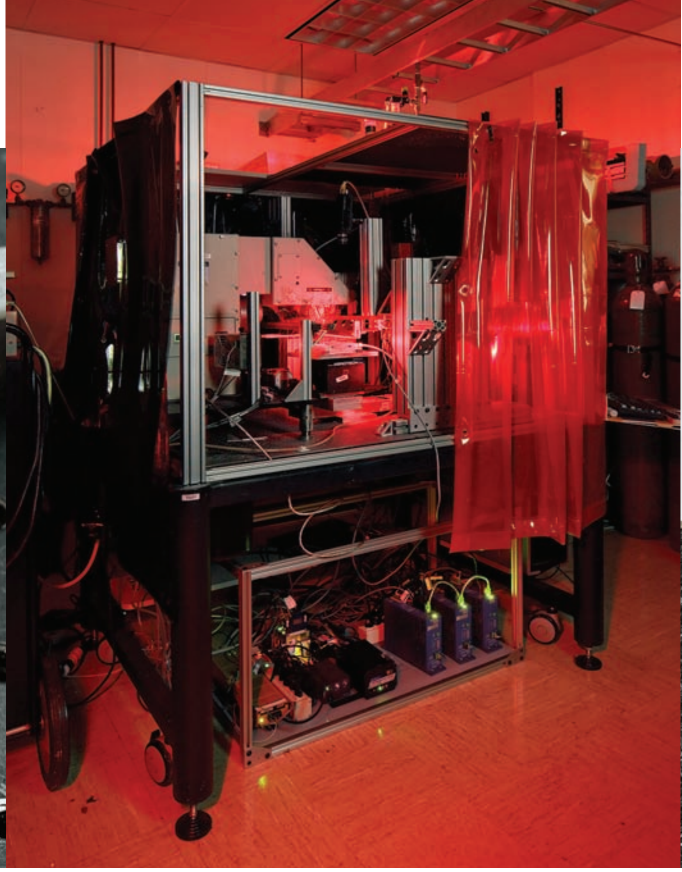
To do it, a laser traces out the shape of the injector's cross-section on a bed of cobalt-chrome powder, fusing the powder into solid form to build up the injector one ultrathin layer at a time. This promises to be less expensive than traditional manufacturing methods, and it should lead to a lighter part—which is to say a better one. The first parts will go into jet engines, says Prabhjot Singh, who runs a lab at GE that focuses on improving and applying this and similar 3-D printing processes. But, he adds, "there's not a day we don't hear from one of the other divisions at GE interested in using this technology."

These innovations are at the forefront of a radical change in manufacturing technology that is especially appealing in advanced applications like aerospace and cars. The 3-D printing techniques won't just make it more efficient to produce existing parts. They will also make it possible to produce things that weren't even conceivable before—like parts with complex, scooped-out shapes that minimize weight without sacrificing strength. Unlike machining processes, which can leave up to 90 percent of the material on the floor, 3-D printing leaves virtually no waste—a huge consideration with expensive metals such as titanium. The technology could also reduce the need to store parts in inventory, because it's just as easy to print another part—or an improved version of it—10 years after the first one was made. An automobile manufacturer receiving reports of a failure in a seat belt mechanism could have a reconfigured version on its way to dealers within days.

Additive manufacturing, as 3-D printing is also known, emerged in the mid-1980s after Charles Hull invented what he called stereolithography, in which the top layer of a pool of resin is hardened by an ultraviolet laser. Various methods of 3-D printing have become popular with engineers who want to create prototypes of new designs or make a few highly customized parts: they can make a 3-D blueprint of a part in a computer-assisted design program and then get a printer to spit it out hours later. This process avoids the up-front costs, long lead times, and design constraints of conventional high-volume manufacturing techniques like injection mold-

Photographs by BOB O'CONNOR

BUILDUP GE made the aircraft engine component on the left by using a laser to melt metal in precise places, beginning with the single layer seen on the right.



ing, casting, and stamping. But the technology has been adapted to only a limited set of materials, and there have been questions about quality control. Building parts this way has also been slow—it can take a day or more to do what traditional manufacturing can accomplish in minutes or hours. For these reasons, 3-D printing hasn't been used for very large runs of production parts.

But now the technology is advancing far enough for production runs in niche markets such as medical devices. And it's poised to break into several larger applications over the next several years. "We've come to the point when enough critical advances are happening to make the technology truly useful in manufacturing end-use parts," says Tim Gornet, who runs the Rapid Prototyping Center at the University of Louisville.

MAKING INROADS

Several techniques can be used to "print" a solid object layer by layer. In sintering, a thin layer of powdered metal or thermoplastic is exposed to a laser or electron beam that fuses the material into a solid in designated areas; then a new coating of powder is laid on top and the process repeated. Parts can also be built up with heated plastic or metal extruded or squirted through a nozzle that moves to create the shape of one layer, after which another layer is deposited directly on top, and so forth. In another 3-D printing method, glue is used to bind powders.

Aerospace companies are at the forefront of adopting the technology, because airplanes often need parts with complex geometries to meet tricky airflow and cooling requirements in jammed compartments. About 20,000 parts made by laser sintering are already flying in military and commercial aircraft made by Boeing, including 32 different components for its 787 Dreamliner planes, according to Terry Wohlers, a manufacturing consultant who specializes in additive processes. These aren't items that have to be mass-produced; Boeing might make a few hundred of them all year. They're also not critical to flight; among them are elaborately shaped air ducts needed for cooling, which previously had to be manufactured in multiple pieces. "Now we can optimize the design of these parts for weight, and we save material and labor," says Mike Vander Wel, director of Boeing's manufacturing technology strategy group. "In theory, this is the ultimate manufacturing method for us." Though the speed limitations of 3-D printing might keep it from ever producing the majority of Boeing's parts, Vander Wel says, the approach is likely to be used in a growing proportion of them.

Boeing's main rival, the European Aeronautic Defense and Space Company (EADS), is using the technology to make titanium parts in satellites and hopes to use it for parts it makes in higher volume for Airbus planes. "We don't yet know what the extent of our use of additive-layer manufacturing there will be yet, but we don't see any show stoppers," says Jon Meyer, who heads research on 3-D printing at EADS's Innovation Works division in England.

GE's jet engine division may be closer than anyone else to bringing 3-D-printed parts into large-scale commercial production. In addition to the fuel injector, GE is also laser-sintering titanium into complex shapes for four-foot-long strips bonded onto the leading edge of fan blades. These strips deflect debris and create more efficient airflow. Until now, each one has required tens of hours of forging and machining, during which 50 percent of the titanium was lost. By switching to 3-D printing, the company will save about $25,000 in labor and material in each engine, estimates

PRESSING PRINT The photo at far left shows an array of metal jet-engine components printed at GE. In the middle is a microprinter that GE uses to test new ways of building things out of ceramic materials. Researchers are using the machine to print the transducers used as probes in ultrasound machines; they believe it might save time and money while improving design. On this page (top) is a transducer made in the printer; at bottom is the same part after being refined and finished in other machines.

Todd Rockstroh, the GE consulting engineer who heads the effort. The blade edge and the fuel injector will start appearing in engines as early as 2013, and they will be integrated into full-scale production runs in the thousands by about 2016.

Meanwhile, says Rockstroh, the company hopes to gain design flexibility by using 3-D printing for more parts. When it recently discovered that a stem in the fuel injector was subjected to excessive levels of heat stress, a redesigned version came out of the printer within a week. "Before, we would have had to redesign 20 different parts, with all the associated tooling," says Rockstroh. "It might not have even been possible." And using 3-D printing to corrugate the insides of some parts can reduce their weight by up to 70 percent, which can save an airline millions of gallons of fuel every year. That prospect has GE looking for ways to print everything from gearbox housings to control mechanisms. "We're going on a major weight-reduction scavenger hunt next year," Rockstroh says.

Automobiles could similarly benefit from lighter parts, and the University of Louisville's Gornet notes that printing processes could cut the weight of valves, pistons, and fuel injectors by at least half. Some manufacturers of ultraluxury and high-performance cars, including Bentley and BMW, are already using 3-D printing for parts with production runs in the hundreds.

CHALLENGES TO OVERCOME

If it weren't for the limitations of the technology, 3-D printing would already be much more broadly used. "Speeds are atrociously slow right now," says GE's Singh. Todd Grimm, who heads an additive-manufacturing consultancy in Edgewood, Kentucky, estimates that the time it takes to produce a part will have to improve as much as a hundredfold if 3-D printing is to compete directly with conventional manufacturing techniques in most applications. That won't happen in the next few years.

Another problem: for now, only a handful of plastic and metal compounds can be used in 3-D printing. In laser sintering, for example, the material must be able to form a powder that will melt neatly when it is hit with a laser, and then solidify quickly. The compounds that meet the necessary criteria can cost 50 to 100 times as much by weight as the raw materials used in conventional manufacturing processes, partly because they're in such low demand that they're available only from small specialty suppliers.

As demand increases with new applications, however, supplier competition should pull prices down dramatically. And the list of available materials is slowly expanding. GE is trying to use ceramics, which would open up new possibilities in engines and medical devices, among other areas.

Simple experience, too, will do much to improve the technology. So far, manufacturers don't have enough data to predict exactly how a part will turn out and how it will hold up, or how production variables—including temperature, choice of material, part shape, and cooling time—affect the results. That can be frustrating, says Singh: "3-D printing often ends up being a black art. A part is made out of thousands of layers, and each layer is a potential failure mode. We still don't understand why a part comes out slightly differently on one machine than it does on another, or even on the same machine on a different day." For example, the layering process tends to build up interlayer stresses in unpredictable ways, so that some parts end up distorted. Porosity can vary within parts as well, leading to concerns about fatigue or brittleness. That could be a big problem in aircraft engines or wing struts. "We know how to make the metals strong enough," says Boeing's Vander Wel. "But we worry about the unpredictability. Can we repeat a result to get 100 parts that are exactly the same? We're not sure yet."

Even with these challenges, time is on the side of 3-D printing, says Vander Wel, and not just because the processes are improving. Engineers are understandably reluctant to embrace a new technology for critical parts when their deadlines and reputations, not to mention the lives of people in airplanes, are at stake. "But younger designers are adapting more quickly," he says. "They're not so quick to say, 'It can't be built this way.'" tr

DAVID H. FREEDMAN, A SCIENCE JOURNALIST BASED IN BOSTON, WROTE ABOUT OPTOGENETICS IN THE NOVEMBER/DECEMBER 2010 ISSUE OF *TR*. HIS LATEST BOOK IS *WRONG: WHY EXPERTS KEEP FAILING US.*

Fire in the Library

Once, we stored our photos and other mementos in shoeboxes in the attic; now we keep them online. That puts our stuff at the mercy of companies that could decide to throw it away—unless Jason Scott and the Archive Team can get there first.

By MATT SCHWARTZ

With reporting by EVA TALMADGE

Until a few months ago, Poetry.com held more than 14 million user-submitted poems, some dating back to the mid-1990s. The site existed to make money: it had ads and at one point sold $60 anthologies to fledgling poets who wanted to see their work in print. But to the users, Poetry.com was much more than a business. It was a scrapbook, a chest for storing precious emotional keepsakes. And they assumed, perhaps naïvely, that it would always be there.

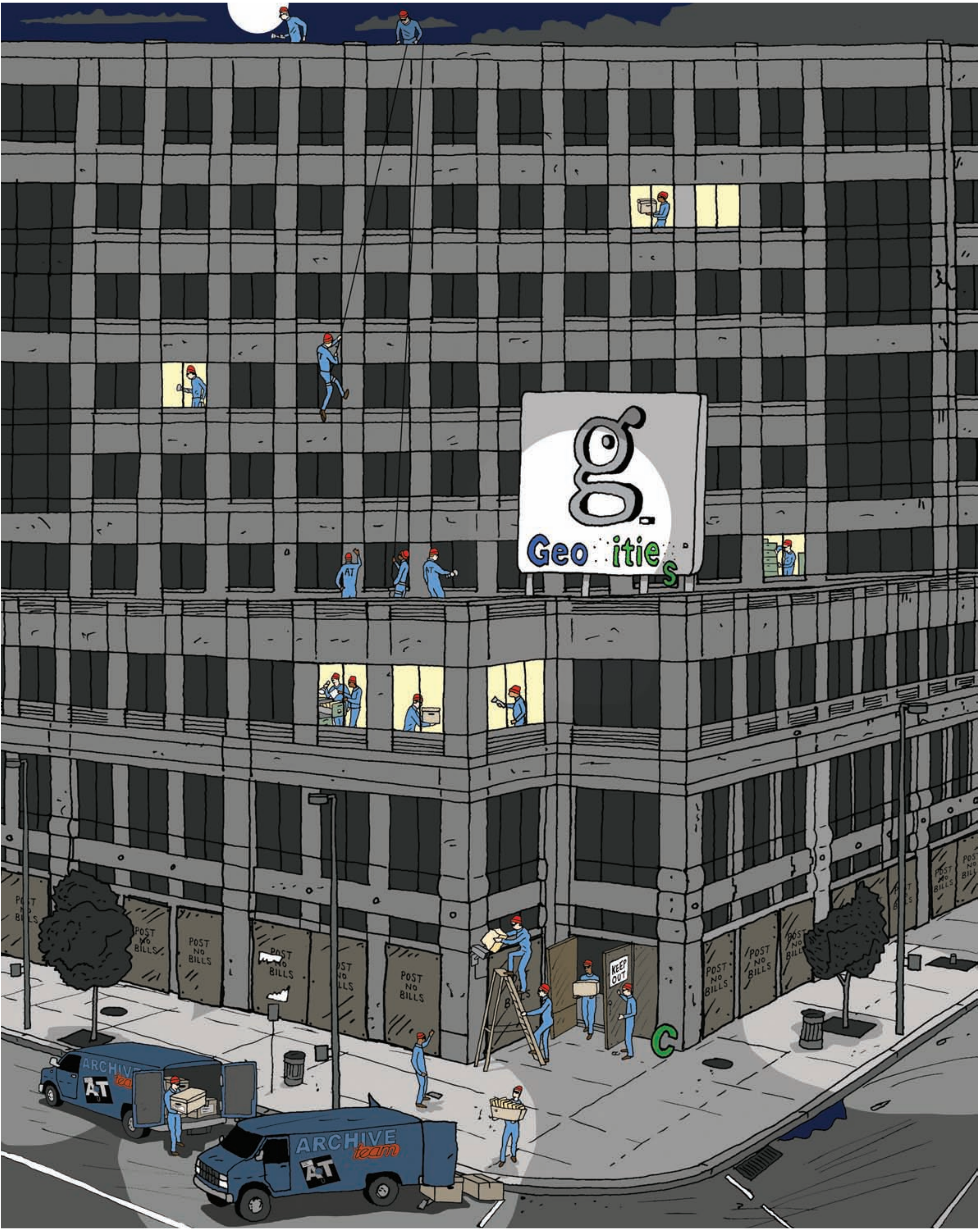
On April 14, the owner of the site abruptly announced that it had been sold and that every poem would be removed by May 4. "Dear Poets," read an e-mail sent to the roughly seven million users. "Please be sure to copy and paste your poems onto your computer and connect with any fellow poets offsite." Users who saw the notice rushed to notify their fellow poets, some of whom had not logged on in months. At 12:01 A.M. on the appointed date, all 14 million poems disappeared from public view. "Your poems are GONE," wrote 1VICTOR, one of the site's users. "This tells me that their intentions is not on the soul of poetry! But the goal of growing in hits."

This trove of poems might have been forever lost had Jason Scott not arrived on the scene. Scott is the top-hat-wearing impresario of the Archive Team, a loosely organized band of digital raiders who leap aboard failing websites just as they are about to go under and salvage whatever they can. After word of what was about to happen at Poetry.com reached the Archive Team, 25 volunteer members of the group logged in to Internet Relay Chat to plan a rescue. "We were like, well, screw that!" Scott recalls. When sites host users' content only to later abruptly close shop, he says, "it's like going into the library business and deciding, 'This is not working for us anymore,' and burning down the library."

Scott and the Archive Team do not seek permission before undertaking one of their raids, though as a rule they only go after files that are publicly available, and Scott says most sites do not complain. They devised code that would copy the poems on Poetry.com and duplicate them in a network of donated server space in such far-flung places as London, Egypt, and Scott's own home in New York state. The members working to save the contents of Poetry.com, who are known by such handles as Teaspoon, DoubleJ, and Coderjoe, met up on one of the Archive Team's IRC channels and divided the poems into blocks, ranging in size from 100,000 to one million files. Most of the team began on the poems that might be considered the best—the ones with the most votes and awards—and worked backward from there.

Unlike other operations, this one encountered resistance. "Poetry.com was actively working against us at every turn," says

Illustrations by PETER ARKLE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ARCHIVE team
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Alex Buie, a high-school senior from Woodbridge, Virginia, who collaborates with Scott on the Archive Team. Buie says someone from Poetry.com e-mailed to complain that the Archive Team was scaring away the company that was about to buy the site. The site even blocked some of the Archive Team members' IP addresses, he adds. But the group persisted. By the time Poetry.com went dark, the team had saved roughly 20 percent of its poems. Today the site is a wasteland, filled with eerie, spam-filled forums and promises by the new owner to restore users' poetry at some point in the future.

CHEATING DEATH

People tend to believe that Web operators will keep their data safe in perpetuity. They entrust much more than poetry to unseen servers maintained by system administrators they've never met. Terabytes of confidential business documents, e-mail correspondence, and irreplaceable photos are uploaded as well, even though vast troves of user data have been lost to changes of ownership, abrupt shutdowns, attacks by hackers, and other discontinuities of service. Users of GeoCities, once the third-most-trafficked site on the Web, lost 38 million homemade pages when its owner, Yahoo, shuttered the site in 2009 rather than continue to bear the cost of hosting it. Among the dozens of other corpses catalogued by the Archive Team's "Deathwatch" are AOL Hometown, Flip.com (a scrapbook site for teenage girls that once had 300,000 members), and Friendster, of which the Archive Team managed to salvage 20 percent. "How many more times will we allow this?" an outraged Scott wrote on his blog after the AOL Hometown shutdown. He compared the lost user home pages to "a turkey drawn with a child's hand or a collection of snow globes collected from a life well-lived."

The personal quality of such data piques Scott: in his eyes, each page that the Archive Team salvages bears the singular mark of the person who made it. Rescued files from Petsburgh, the GeoCities subdomain devoted to pets, include a memorial to Woodro, a Shar-Pei who lost his battle with lung cancer on January 5, 1998. Woodro apparently loved Jimmy Buffett, so his owners paid tribute to his life with the song "Lovely Cruise." It is minutiae like these—evidence of everyday people expressing themselves in a particular place and time—that the Archive Team rescues by the thousands.

Scott's interest in technology, which began with a childhood love of electronics and early personal computers, bloomed in the 1980s and early '90s with the birth of digital bulletin board systems. In 1990 he and a friend created TinyTIM, a multiplayer virtual adventure that's now the longest-running game of its kind. Ten years later, Scott founded Textfiles.com, dedicated to preserving mid-1980s text files "and the world as it was then," bulletin board systems and all. In 2009, he founded the Archive Team, and last March he became an official employee of the Internet Archive, the San Francisco–based nonprofit behind the Wayback Machine, Open Library, and other projects to preserve online media. The Archive Team acts independently and has no formal affiliation with the Internet Archive, but data rescued by the Archive Team often ends up stored on the Internet Archive's servers. "I didn't want to bureaucratize the guy," says the Internet Archive's founder, Brewster Kahle, who hired Scott. "The question for us is how to have a relationship with a volunteer organization in a way that's not stifling from their perspective or frightening from ours." Scott's dual role allows the Internet Archive to take selective advantage of the Archive Team's more aggressive data-gathering techniques while maintaining an arm's-length relationship. Many differences between the two groups can be summed up by the icons that appear beside their URLs in Web browsers—for the Internet Archive, a classical temple, and for the Archive Team, an animated hand flipping visitors the bird.

During my reporting for this article, Scott refused to speak with me for reasons that he declined to explain, but when contacted by a second reporter who also said she was working for *Technology Review*, he discussed his life and work at length in e-mails and phone calls. Born Jason Scott Sadofsky, he is 41 years old and

Part of the appeal of volunteer projects like the Archive Team is that they offer a sort of time machine back to an online world that was less about money and more about fun.

divorced. He lives with his brother's family about 70 miles north of New York City in Hopewell Junction, near the Hudson River. In the backyard is a storage container he calls the "Information Cube," which holds his vast collection of obsolete electronic equipment, computer magazines, and floppy discs, all part of his broader calling as an independent historian of the computer. In 2005, Scott created a five-hour documentary on early bulletin board services, and in 2009 he raised $26,000 in donations to support his rescues of digital history. His second documentary film, *Get Lamp*, about text-based computer games from the 1980s, debuted in 2010. Scott also evangelizes for data preservation on the tech-conference circuit, where his affinity for the old is sometimes reflected in his wardrobe. For example, he has been known to deliver a presentation in steampunk regalia—aviator-style goggles, a velvet jacket, and the top hat. Day to day, the widest outlet for his showmanship is the 1.5-million-follower @sockington Twitter feed written in the voice of his cat, Sockington, who makes such faux-naïf kitty quips as "#occupylitterbox" and "crunked on nip." "He is like a 19-year-old guy in a 40-year-old body," says Buie.

With his enthusiasm for archaic technologies, Scott is a throwback to the Internet's early days, when impassioned amateurs would banter on the WELL or hash out the new medium's technical specifications in request-for-comment papers, along with computer scientists from government and academia. The online community was smaller then, and more countercultural. Too primitive to attract major outside investment, the medium spent the 1980s guided by people like Jason Scott. Part of the appeal of volunteer projects like the Archive Team is that they offer a sort of time machine back to an online world that was less about money and more about fun.

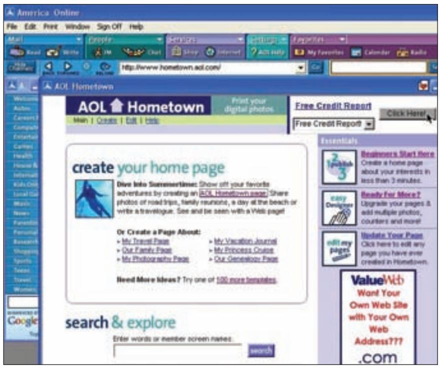
DOODLES AND MEMORIES

Typically, Archive Team members extract data from failing sites using a crawling program like GNU Wget, which lets them quickly copy every publicly available file. The files are then sent to the Internet Archive for storage, or uploaded to one of the loose network of Archive Team servers scattered around the world. The hardest part, Scott explains, is knowing when a site is going down without warning. That happened to Muammar el-Qaddafi's website during the Libyan revolution that ended in his death. "It's an art, not a technical skill," Scott says. An Archive Team user who works under the handle "Alard" was able to copy Qaddafi's site, including videos and audio files of the late dictator. Now these materials are freely available to anyone.

Another recent rescue: Italy's Splinder.com, which is host to half a million blogs and announced its impending closure in a November blog post. Scott heard about Splinder through the Archive Team's grapevine of volunteer archivists, who will often send him e-mail and Twitter messages or add a page directly to the Archive Team's wiki. "People put out a bat signal," Scott says. By November 24, word of Splinder's troubles had reached Scott. More than a dozen members of the Archive Team "went in with guns blazing," he says, racing to copy as many of its 55 million pages as they could, causing the site to crash twice. Ultimately, Splinder's owners acquiesced to angry users and pushed the shutdown date back to January 31.

The next phase of a typical Archive Team mission is less exciting than ripping as much information as possible from a website before it disappears, but just as necessary for the salvaged data to be of any use. Archivists check the integrity of the downloaded data and then distribute it for storage. Larger collections may be released as

SALVAGED MEMENTOS
A sampling of the sites rescued by the Archive Team



AOL HOMETOWN
Once home to 14 million user-generated pages, it was shuttered in 2008. That inspired Scott, who said an "anthropological bonanza" was about to be lost "because someone had to show that they were cutting costs this quarter."

GEOCITIES
GeoCities was founded in 1994 and spawned millions of user-created pages in the early days of the Web. It was purchased by Yahoo in 1999 and closed in 2009.

FLIP.COM
About 300,000 teenage girls once kept virtual scrapbooks known as "flipbooks" at Flip.com, until Condé Nast changed its social-networking strategy and closed the site in 2008.

FRIENDSTER
It heralded the social-networking craze, but by 2009 the party had moved on, and a Malaysian company bought the site to focus it on the Asian market. Last year Friendster warned that it would delete old photos and profiles.

ALGATHAFI.ORG
The official site of Muammar el-Qaddafi came under attack during the Libyan revolution. Now the dictator is dead, but his data lives on.

SPLINDER
Founded in 2001, Italy's Splinder hosts millions of its users' blog pages. It plans to close at the end of January, so the Archive Team is in the midst of copying the whole site.

torrents, which anyone can download over the peer-to-peer service BitTorrent, on sites like thepiratebay.org. The GeoCities archive was so big that at first Scott put out a call asking anyone with an available terabyte-sized hard drive to mail it to his home, where he would load the files and arrange for return postage. More than a dozen people from Scott's network volunteered to help safeguard the GeoCities cache until it was ready to be released as a torrent.

The Archive Team requires "a certain kind of person who's sort of reckless while still being methodical," says Duncan B. Smith, who works with the group under the handle "chronomex." "People live for the big efforts where people mobilize and download the fuck out of some website run by assholes. After the fire's out, though, you still have to stick around to clean the fire truck and put the gear away. You have to upload your data to the centralized dump to be collated. Then you have to talk over why your data seems slightly broken. That's the boring part."

Is it legal to copy stuff from websites without permission? U.S. courts haven't made a clear determination. Andy Sellars, a staff attorney at the Citizen Media Law Project, says he would argue that it counts as "fair use" under copyright law. However, he notes that the Archive Team's torrents don't offer a mechanism for copyright holders to demand that certain material be taken down, which could hurt its case in a court. "If you look at the letter of copyright law, it's pushing the envelope," says Jonathan Zittrain, codirector of Harvard's Berkman Center for Internet and Society. But because the Internet Archive has been engaged in similar work for years, Zittrain says, "now the radical move would be for the courts to forbid it. Soon it will be another part of the furniture."

THE DATA HOARD

GeoCities is probably the best example supporting Scott's argument that apparently silly or worthless data can have unanticipated cultural value. Today the 652-gigabyte torrent that the Archive Team made available in October 2010 is free to anyone who wants to have a look. The most impressive project this release has spawned is the DeletedCity, a ghostly video interface that allows users to explore various GeoCities subdivisions and content. On the micro level, the Archive Team has been able to dig up and return the content of individual GeoCities users, like a late World War II veteran who had put his photo archive on the site. After GeoCities went down, the Archive Team uploaded the old pictures to a USB drive and mailed it his widow, free of charge. Phil Forget, a 26-year-old programmer in New York, used the GeoCities torrent to dig up his old images from the Japanese anime series *Dragonball Z* as well as animated caricatures he had made of his high-school teachers. The material isn't as significant to him as the widow's photographs were to her, but it is far from trivial. "It's like if you went back to your mom's house and found the doodles on the back of your marbled notebook, from fourth or fifth grade," Forget says. "You get this rush of memories."

Listening to Scott talk about the importance of our collective "digital heritage" makes the loss of sites like GeoCities feel as tragic as the burning of the Library of Alexandria, a vast archive of ancient texts, many of which existed nowhere else. (The library has a joking listing on the Archive Team's site, which lists its URL as "none" and the project's status as "destroyed.") Scott scoffs at the suggestion that material like the verses on Poetry.com might not be worth saving; he notes that the New York Public Library stores old menus in its rare-books collection. "No one questions that," he says.

Scott's two holy grails are the archives of Compuserve, which was one of the major online services of the dial-up era before eventually being absorbed by AOL, and those of a past incarnation of MP3.com, which formerly was devoted exclusively to independent musicians who wanted to share their work. "I bristle when I see that level of culture wiped away," he says. Scott believes that the archives of both sites must be out there somewhere; perhaps they are on reels of magnetic tape gathering dust in a garage. Sometimes he can appear to have an almost Peter Pan-ish unwillingness to accept the passage of time and the way information gives way to entropy. To him, the idea of data that cannot be saved is almost as heretical as the notion of data that is not worth saving.

Scott approaches today's multibillion-dollar repositories of user data—sites like Facebook, Google, and Flickr—with intense skepticism. The sister page of the Archive Team's Deathwatch is called "Alive ... OR ARE THEY?" and makes it abundantly clear that the data ethics of Mark Zuckerberg and Larry Page are being carefully watched. Facebook "seems stable at the moment," says the Archive Team, while Google "wants you to think they will be here forever." Some posters on the Archive Team wiki have already criticized Google for closing down Google Labs, a section of the site devoted to experimental projects, and for warning that it might stop hosting previously uploaded content at Google Video. "Don't trust the Cloud to safekeep this stuff," Scott has warned.

"I get very cranky," he says. "You know the Google ad where the parent is recording family memories on YouTube, and keeping photos on Picasa, and telling his kid, 'I can't wait to share these with you someday'? Well, not if you keep it on Google. They make these claims that you can keep things forever, but in fact it's all temporary."

Buie, the high-school senior, argues that keeping old data serves a purpose whether or not anyone is using it now. "Take the Friendster stuff," he says. "Maybe no one will look at it until 2250. That doesn't matter to me. What matters is that the knowledge is there." Buie found the Archive Team through his avocation as a historian of early hardware. He had gone to a "too good to waste" section of his county's dump, looking for early computers to refurbish and add to his collection. After bringing home an Apple II and scouring the Web for information on spare parts, he saw a reference to a defunct GeoCities page that had the information he was looking for, and his search for this page led him to the Archive Team's GeoCities project. Now Buie frames his work with Scott as part of the solution to a broader cultural problem on the Web. "There isn't enough focus on the past, on where we came from," he says. "And if you forget the past, then the future becomes meaningless, because you don't even know how you got to where you're standing."

As Scott continues to project his message with maximum bombast, it appears that some of the Web's leading brands are coming around to his views. When Google launched its social-networking service Google+ last June, it introduced a new feature called Takeout that would combine users' posts and export the files for them. Gmail already let users export their contact lists, making it easier to switch to competitors' products. "I personally won't be happy until every last bit of your data is available through Takeout," says Brian Fitzpatrick, an engineering manager at Google who leads the company's data liberation efforts. He says Google should do it so that users trust the company: "It's not because we're nice." Though Facebook declined to comment for this article, it has added a Takeout-like "Download a Copy" function for the photos, messages, and other content users keep on the site.

As for Scott, he is looking further ahead. He's already planning for that distant day when his most important piece of metadata—the knowledge he has amassed of his own collections—will go blank. "Mortality?" he says. "I have a distributed array of servers. Whatever I acquire, I share out as fast as possible. None of it is sitting on a hard drive in one guy's house." tr

MATT SCHWARTZ IS A FREELANCE WRITER WHOSE WORK HAS APPEARED IN *WIRED*, THE *NEW YORKER*, AND THE *NEW YORK TIMES MAGAZINE*. HE REVIEWED FOURSQUARE AND SCVNGR IN THE MARCH/APRIL 2011 ISSUE OF *TECHNOLOGY REVIEW*.

The Mystery Behind Anesthesia

Mapping how our neural circuits change under the influence of anesthesia could shed light on one of neuroscience's most perplexing riddles: consciousness.

By COURTNEY HUMPHRIES

A video screen shows a man in his late 60s lying awake on an operating table. Just outside the camera's view, a doctor is moving his finger in front of the man's face, instructing him to follow it back and forth with his eyes. Seconds later, after a dose of the powerful anesthetic drug propofol, his eyelids begin to droop. Then his pupils stop moving. Only the steady background beeping of the heart monitor serves as a reminder that the man isn't dead. "He's in a coma," the doctor, Emery Brown, explains. "General anesthesia is a drug-induced reversible coma."

As an anesthesiologist at Massachusetts General Hospital (MGH), Brown is constant witness to one of the most profound and mysterious feats of modern medicine. Every day, nearly 60,000 patients in the United States undergo general anesthesia, enabling them to survive even the grisliest operations unaware and free of pain.

But though doctors have been putting people under for more than 150 years, what happens in the brain during general anesthesia is a mystery. Scientists don't know much about the extent to which these drugs tap into the same brain circuitry we use when we sleep, or how being anesthetized differs from other ways of losing consciousness, such as slipping into a coma following an injury. Are parts of the brain truly shutting off, or do they simply stop communicating with each other? How is being anesthetized different from a state of hypnosis or deep meditation? And what happens in the brain in the transition between consciousness and unconsciousness? "We know we can get you in and out of this safely," Brown says, "but we still can't quite tell you how it works."

Brown, who is also a neuroscientist and professor at MIT, aims to transform anesthesia from a solely clinical tool into a powerful instrument for studying the most basic questions about the brain. Understanding what happens to the brain under anesthetic drugs, he believes, will help make anesthesia safer and more effective, with fewer side effects. It could also lead to novel treatments for coma and other brain conditions—and to insights into fundamental questions in neuroscience, including the nature of consciousness itself. "Anesthesiology is a form of neuroscience," says George Mashour, an anesthesiologist and neuroscientist at the University of Michigan. "And what we do on a daily basis is modulate virtually every aspect of the nervous system."

FROM CHATTER TO CHANT

Neuroscience has often benefited from natural experiments—patients who lose their ability to remember, produce language, or regulate their emotions after parts of their brains are damaged or have to be surgically removed. Anesthesiologists preside over an analogous experiment every day: they watch elements of consciousness disappear. Under general anesthesia, for instance, patients lose pain perception, awareness, memory, and the ability to move. An anesthesiologist can influence each of these changes in different ways by varying the dosages and types of drugs used.

"By taking away different functions that we associate with consciousness," Brown says, "we might be able to start piecing together parts of the jigsaw puzzle." Neuroscientists could begin to do for consciousness what they have done with memory and language.

Photograph by MARK OSTOW

GOING UNDER
Emery Brown's quest to understand how anesthesia affects the brain could provide crucial clues about what goes wrong in certain disorders.

Brown is part of a small but growing group of anesthesiology researchers who are using the electroencephalogram (EEG), a tool for monitoring the brain's electrical activity, to systematically probe each aspect of anesthesia in humans and animals. EEG-based brain monitors are already a common sight in operating rooms; some anesthesiologists track the brain activity of their patients with commercially available monitors that use algorithms to transform EEG signals into crude indexes. (Others track only physical signs such as heart rate and blood oxygen levels.) But few of them, he says, spend time looking at the raw EEG data.

Brown, however, has a different perspective from most anesthesiologists; he's also a statistician. After receiving both an MD and a PhD from Harvard in the late 1980s, he pursued the two paths separately, working in the operating rooms of MGH while heading a research laboratory focused on developing signal-processing algorithms to extract information from biological data.

Brown didn't appreciate the neuroscience experiments taking place in front of him each day during surgery until one of his colleagues suggested doing a study on anesthetized patients. Watching the process unfold, "you start realizing that parts of the brain don't shut down all at the same time," he says. "There is a hierarchy, there is a gradation to it."

The same is true when the drugs wear off. Typically, the most basic brain functions come back first—breathing returns, and then, as the areas of the brain stem controlling salivation and tear ducts revive, patients' mouths fill with saliva and their eyes water. They swallow and cough as areas controlling sensation to the throat become active. Finally their eyes move, and then they respond to the outside world. Later the grogginess will lift and complex brain functions will resume. "When you pay attention and you watch those transitions, it's just amazing," Brown says. "We would truly be remiss if we didn't then move forward and try to figure out what these states are, what's actually happening in the brain, and then think of new ways to improve the anesthesia process."

One of the things that struck Brown from watching his patients' EEGs is how quickly and completely drugs like propofol can alter brain activity. As patients enter an anesthetized state, the normal pattern of low-intensity but high-frequency waves shifts to one of less frequent but more intense pulses—as if the constant chatter of the brain had given way to a chant. The location of activity shifts from the back of the brain to the front. Although it's possible to take patients into such a deep state of unconsciousness that their EEG is essentially flat, in most cases bursts of EEG activity alternate with periods of relative inactivity that can last for minutes. The brain processes appear "highly organized," he says. "There are very regular patterns in time, and very regular patterns in space."

Brown says that some drugs will decrease the frequency of brain waves seen in EEG readings, resulting in slow, regular oscillating waves across large areas of the brain. Other drugs cause certain areas to show fast, regular oscillations. Because anesthesiologists usually give a cocktail of drugs to each patient, these effects can happen simultaneously. The result, says Brown, is like a jammed signal: "Either way, [the different parts of the brain] can't communicate."

Over the past few years, other EEG studies have supported the idea that anesthesia doesn't simply shut the brain down but, rather, interferes with its internal communication. Mashour's research, for instance, has shown that feedback between the front and back of the brain is interrupted during general anesthesia, leading to a disconnect between different brain networks. That feedback is thought to be important for consciousness.

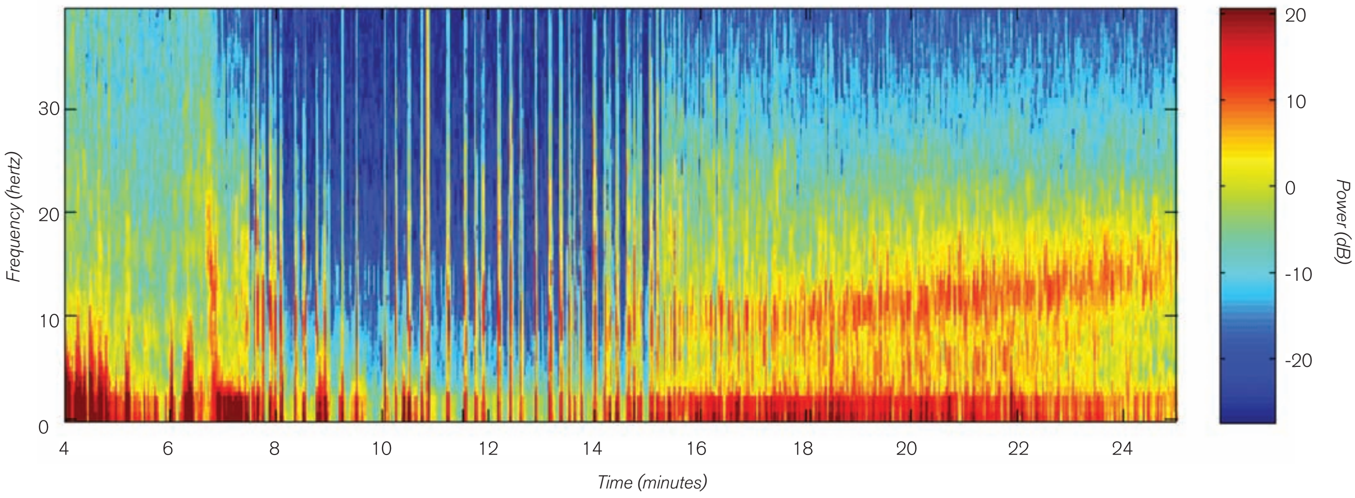
Similarly, Anthony Hudetz, an anesthesiologist at the Medical College of Wisconsin in Milwaukee, says that anesthesia doesn't simply switch off the senses. Hudetz administers anesthesia to human volunteers at lower-than-clinical levels to observe their brains as they slip into unconsciousness. "What we find is that the anesthetized brain is still very reactive to stimuli," he says; both EEG and functional magnetic resonance imaging (fMRI), an indirect method of measuring brain activity, show response to light and sounds. But somehow that sensory information is never processed and integrated into the type of activity necessary for conscious awareness.

Better understanding of these changes could point a way toward new treatments for brain injury and other disorders. The patterns of highly structured oscillations in patients given anesthetic drugs are similar to states seen in people who lose consciousness during epileptic seizures or who are in deep comas. And the semiconsciousness that results from low doses of the drugs resembles ordinary wakefulness or the early stages of falling asleep. But figuring out exactly how and why these patterns are related will take closer scrutiny.

MAPPING THE COMMUNICATION BREAKDOWN

In order to truly understand whether communication between different brain areas has broken down, scientists need a way to map the activity of these regions and the interactions between them in greater spatial detail. For that, they are turning to fMRI, which measures the changes in blood flow associated with neural activity *(see "Raising Consciousness," January/February 2007)*.

Working with bioengineer Patrick Purdon and other colleagues at MGH, Brown has developed a way to simultaneously take EEG recordings and perform fMRI scans on patients as they enter a deeply anesthetized state. Brain imaging in human subjects undergoing anesthesia is tricky because it requires anesthetizing people within a scanner and outside a normal operating room. Brown and his colleagues found a way to solve the technical and safety problems: they recruited volunteers who had already received tracheostomies, or surgical holes in the throat. That meant a tube could readily be used to restore their breathing in an emergency. In 2009, the researchers demonstrated that they could safely record both EEG and fMRI data on people under anesthesia; now they are



CHARTING THE UNCONSCIOUS This spectrogram shows EEG recordings from a patient undergoing general anesthesia. Two doses of the intravenous anesthetic propofol lead to bursts of activity (minute seven). Then an inhaled anesthetic, isoflurane, is added, and at minute 14, a characteristic pattern of slow-wave and alpha oscillations begins. Surgery ends at minute 16, and the isoflurane is switched off. The EEG gradually shifts to high-frequency, less intense oscillations.

COURTESY OF EMERY BROWN

working to correlate the imaging and EEG data with the observable changes seen as patients enter an anesthetized state.

Brown is also working with Purdon to study epilepsy patients who've had electrodes implanted into their brains for several days so that clinicians can record and locate seizures. When the patients undergo surgery to remove the brain areas identified as seizure sites, the electrodes record brain waves as anesthesia is administered. These electrodes collect data about a much smaller part of the brain than EEG or fMRI, but the resolution is much higher, allowing scientists to get a sense of what happens in the brain at the cellular level as the patient is anesthetized. Follow-up studies in animals could yield even greater detail by allowing the researchers to implant electrodes more extensively and in precise locations. The researchers will be able to document—from within the brain itself—how activity changes as the brain slips into and out of consciousness.

PIECING TOGETHER CONSCIOUSNESS

If you can systematically catalogue how the brain loses consciousness under the influence of anesthetic drugs, can you deduce what consciousness consists of?

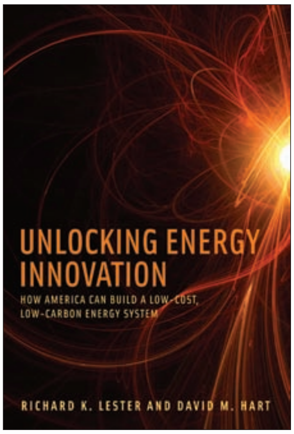
Brown is quick to point out that he doesn't explicitly study consciousness; it's a messy problem, and many neuroscientists avoid the very word. His approach is to study what he calls altered states of arousal. These include anesthesia, sleep, coma, hypnosis, and meditation, as well as aspects of disorders like schizophrenia, epilepsy, and Parkinson's disease. He believes that understanding how the brain functions when it deviates from its normal conscious state will inevitably shed light on what consciousness is.

Anesthesia studies have already cast doubt on one popular theory, which links consciousness to a particular type of brain wave with a frequency around 40 hertz. Mashour points out that research in anesthesia shows these waves can exist even when patients are unconscious. But the patterns that anesthesiologists see do support another theory: that consciousness emerges from the integration of information across large networks in the brain. Hudetz says that while different drugs have different chemical structures and different effects, such as blocking memory or sedating the brain, "if we give any of these drugs at a high enough dose, at some point they do remove consciousness. How do we get this common end point by such a variety of drugs working through different molecular mechanisms?" One explanation is that because consciousness arises from the complex interaction of many kinds of activity, it can be disrupted in many different ways.

Brown hopes the insights gleaned from this work can spill into other areas. Knowing more about how the brain functions under anesthesia could help researchers detect brain activity in people in vegetative states, revealing that they may perceive more than previously thought. The safer anesthetics that might emerge from the research could be useful in sleep medicine, and ways of reviving cognitive function in anesthetized patients might give rise to strategies for helping bring people out of comas. Ketamine, a commonly used anesthetic, has shown some promise as a treatment for depression; other anesthetic drugs could also prove to have effects that lend themselves to treating psychiatric illness. Studying the loss of consciousness in anesthesia will not just illuminate the nature of the conscious mind but bring these states of dampened or altered consciousness out of the shadows. tr

COURTNEY HUMPHRIES IS A SCIENCE WRITER AND THE AUTHOR OF *SUPERDOVE: HOW THE PIGEON TOOK MANHATTAN ... AND THE WORLD.*

The MIT Press



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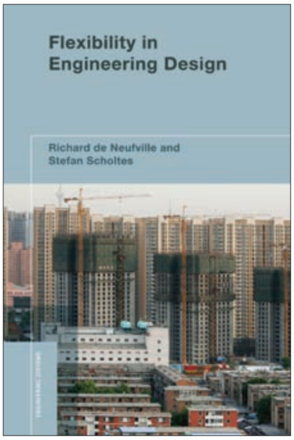

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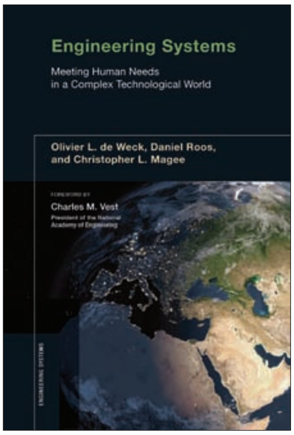

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Disruptive Innovation

THE BIG QUESTION

The Empires Strike Back

How Xerox and other large corporations are harnessing the force of disruptive innovation.

By SCOTT D. ANTHONY and CLAYTON M. CHRISTENSEN

It has been a long time since anyone considered Xerox an innovation powerhouse. On the contrary, Xerox typically serves as a cautionary tale of opportunity lost: many obituaries of Steve Jobs described how his fateful visit to the Xerox Palo Alto Research Center in 1979 inspired many of the breakthroughs that Apple built into its Macintosh computer. Back then, Xerox dominated the photocopier market and was understandably focused on improving and sustaining its high-margin products. The company's headquarters became the place where inventions in its Silicon Valley lab went to die. Inevitably, simpler and cheaper copiers from Canon and other rivals cut down Xerox in its core market. It is a classic story of the "innovator's dilemma." Xerox struggled to defend against threats at the low end of its business, failed to create growth in new markets, and found itself on the brink of irrelevance, if not extinction.

But now Xerox is turning things around. In the fall of 2009, the first order of business for its new CEO, Ursula Burns, was to buy Affiliated Computer Services for $6.4 billion. The 74,000-employee services company had built a powerful new business model by taking over document management from corporations, state governments, and law firms, typically using non-Xerox equipment. The clients found outsourcing simpler and cheaper than doing it themselves.

Under Burns, Xerox began redefining its mission. "I kept asking people: *What is it that we do?*" she said in a recent speech at the Churchill Club. "The answer was always: 'We're a copier company, a printer company, a document company.' 'No, that's not what we do,' I said. 'We help companies transform very complex and burdensome business processes.'"

As Burns plunged Xerox into the services business, she devoted R&D resources—at the storied PARC lab and elsewhere—to developing simple Web-based document tools such as BlitzDocs, which enables banks to streamline the mortgage approval process, and CategoriX, which helps law firms increase their analytical capabilities and manage millions of documents.

This is *disruptive innovation*—making the complicated simple, making the expensive affordable, driving growth by transforming what exists and creating what doesn't. And it appears to be working: Xerox's outsourcing and software business is growing quickly, with profits during the first three quarters of 2011 up 13 percent over 2010. Within three years, Burns expects two-thirds of Xerox's total revenue to come from the services side of the business, compared with around half now.

In the past, Xerox's success would have been an anomaly. Less than a decade ago, when we were finishing the book *The Innovator's Solution* (Christensen as primary author and Anthony as his research associate), we highlighted the fact that disruptive innovations are typically introduced by startups, the rebel forces in the business universe. The book named 100 companies that had successfully created disruptive businesses since the 1870s in industries from accounting software to excavation. A full 85 percent of them were new companies formed specifically to commercialize disruptive technologies.

We define disruptive technologies as those that offer "good enough" solutions to new groups of consumers, often at radically lower prices. Disruptors often fly below the radar of incumbent businesses, which have strong short-term incentives to deliver better-performing, higher-margin products to their most demanding customers. They initially view disruptive innovations as undesirable for their customers—if they see them at all. But then the performance of the disruptive technology keeps improving, to the point where it can topple a corporate giant. Just think about how inconsequential e-books were to brick-and-mortar bookstores three or four years ago. Then came the price and performance improvements of Amazon's Kindle, and the introduction of Apple's iPad, and suddenly Borders was forced into liquidation.

However, analysis we have done at Innosight suggests that a growing number of long-established market leaders like Xerox are turning disruption from a threat into an opportunity. Throughout the 1980s and 1990s, only about 25 percent of disruptive innovations we tracked in our database came from such incumbents, with the rest coming from startups. But during the 2000s, 35 percent of disruptions were launched by incumbents.

In other words, the battle seems to be swinging in favor of the Empire, as the following examples confirm.

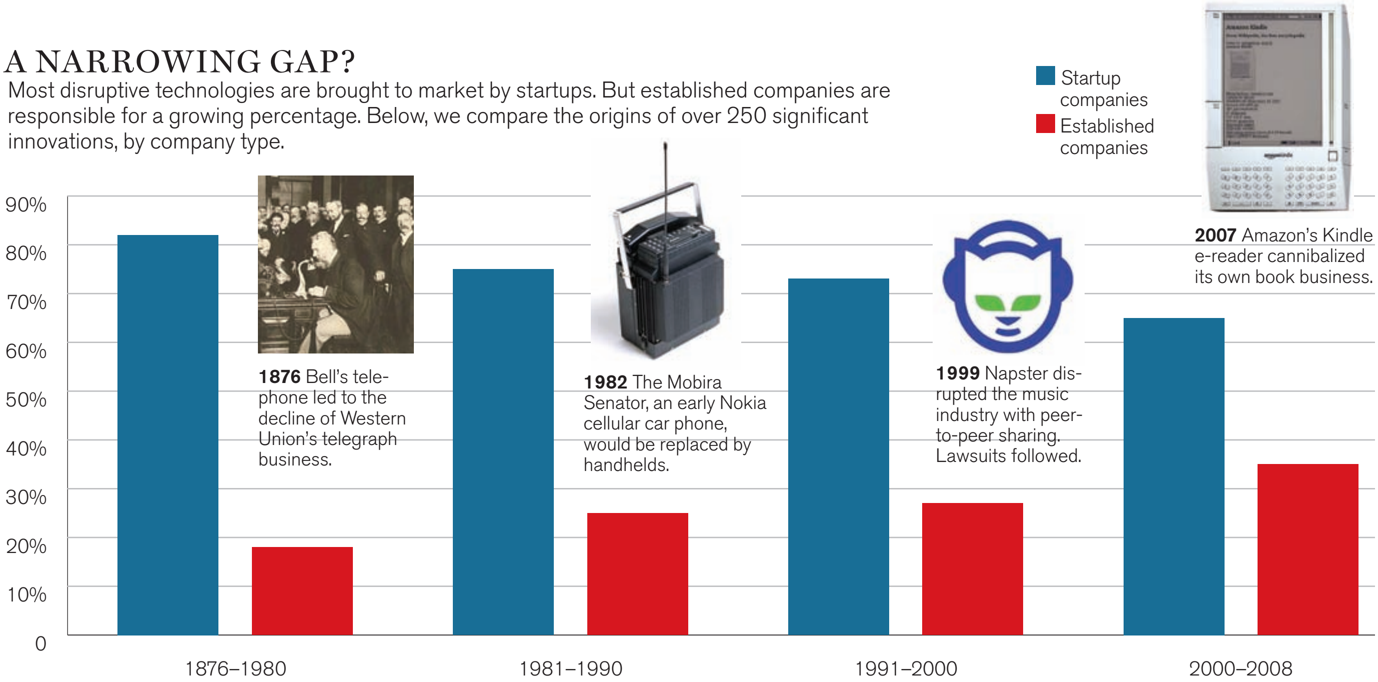
■ General Electric preëmpted competitors by developing low-cost electrocardiogram devices to sell to doctors in rural India and China, who historically could not afford more complicated devices.

■ Startups like Tesla Motors have introduced high-priced electric cars, but incumbents like General Motors and Nissan developed affordable models, potentially disrupting the business of oil companies.

■ Dow Corning expanded a self-service Web-based distribution channel called Xiameter to market low-cost silicone materials, disrupting its own commission-based sales force.

A NARROWING GAP?

Most disruptive technologies are brought to market by startups. But established companies are responsible for a growing percentage. Below, we compare the origins of over 250 significant innovations, by company type.



Source: Innosight

■ Microsoft came out with Kinect, the gesture interface system that appeals to new classes of consumers who see joystick gaming controls as too complicated.

There seems to be something important going on. Empires are striking back at rebel forces. Why is this happening? And what does it mean?

One explanation is good old-fashioned survival instincts. After seeing so many corporate icons toppled, companies finally recognize that their competitive advantage can disappear quickly. Just consider how technology companies such as Nokia and Research in Motion are cratering, while Hewlett-Packard has gone through wrenching leadership changes and even considered leaving the personal-computing business. Today's tightly interconnected markets make it harder for a company to be deaf to the roar of change.

The increasing pace of disruptive threats isn't merely anecdotal. Turnover among the world's largest companies is accelerating. Consider *Fortune*'s bellwether list of the 500 largest companies in the United States. The list would seem to change slowly; after all, in 2011 companies needed close to $50 billion in revenue to make it to the top 50 (up from $30 billion in 2001). But in the past 10 years, 40 percent of the top 50 companies have changed. Some high-flyers, like Compaq and Sun Microsystems, fell off the Fortune 500 list entirely because they were acquired, and others, such as Enron and Kmart, essentially disintegrated. Still other recent victims of technological disruption: Blockbuster, Unisys, Tribune Co., and CA Technologies (formerly Computer Associates).

Another factor attuning companies to the power of disruption is the search for profits in developing economies. Winning in emerging markets often requires lower prices and different business models—two hallmarks of disruption.

In the General Electric example, when the medical-equipment division charged local teams with developing electrocardiogram devices to sell in rural India and China, GE followed a classically disruptive approach. It developed a stripped-down, low-cost version of its established technology, created a new distribution channel, and arranged for local financing to help get the devices into the hands of rural practitioners. These breakthrough strategies have helped GE boost growth in emerging markets.

Among incumbent companies that have benefited from disruption, we see three patterns repeat. Generally speaking, they maximize their chances of success by:

Pushing beyond core competencies. Over the past decade Amazon.com has created new businesses in retailing, e-readers, and cloud computing. When we asked CEO Jeff Bezos how he did it, he said, "If you want to really continually revitalize the service you provide the customer, you can't stop at 'What are we good at?' You have to ask, 'What do our customers need and want?' And no matter how hard it is, you better get good at those things." Pushing boundaries helps companies spot disruptive signals early—especially if they pay attention to new competitors that serve customers who were previously ignored.

Embracing business-model innovation. Driving disruption requires moving beyond purely technological innovation to consider new ways of creating, capturing, and delivering value. The clearest example of this is Apple, whose market capitalization has soared from $3 billion a decade

LIBRARY OF CONGRESS (BELL); JON 'SHAKATAGANAI' DAVIS (KINDLE)

ago to around $340 billion today. Sure, it has introduced new computing devices, but central to its success have been iTunes, the App Store, new pricing models, and innovative retail stores.

Managing the old and the new differently. Over the last decade IBM's Emerging Business Opportunities (EBO) program has helped the company succeed in new markets like blade servers and networked data storage. One key is not judging new technology solely on its potential financial return. Instead, IBM evaluates the success of its EBO teams primarily according to whether managers learn from early failure and make adjustments in response.

The surge in incumbent-led disruption means different things to different people. If you're an entrepreneur and your strategy assumes that the market-leading incumbent will ignore you, you ought to rethink your business plan. The evidence suggests that incumbents are waking up and recognizing that they can't cede markets to new entrants. Perhaps a generation ago General Motors or Nissan would have ignored upstart electric-vehicle makers like Tesla. Today's titans are responding aggressively. Tesla has smartly sought to license key parts of its technology to market leaders like Toyota. Entrepreneurs who are dead set on defeating market leaders should consider novel ways to work with them instead.

If you are a senior executive inside a large company, make sure you are thinking about ways to drive new disruptive growth. The next time you and your colleagues talk about strategy, ask how many projects you are working on that have the power to create new markets or disrupt and reframe existing ones. If your coworkers all look at each other blankly, your growth strategy is insufficient. Over time, there's no escaping it: if you don't disrupt others, you can be sure that either new or old competitors will destroy you. BI

SCOTT D. ANTHONY IS MANAGING DIRECTOR OF INNOSIGHT ASIA-PACIFIC AND THE AUTHOR OF *THE LITTLE BLACK BOOK OF INNOVATION*. CLAYTON M. CHRISTENSEN IS COFOUNDER OF INNOSIGHT AND A PROFESSOR AT HARVARD BUSINESS SCHOOL.

CREATIVE TYPES
Thomas Heermann (left) and Chris Cheung in portraits drawn with their SketchBook app.

SUSAN MURTAUGH AND JACQUES PENA/AUTODESK

CASE STUDIES

How Autodesk Disrupted Itself with an App

A maker of high-end design software accidentally discovers a consumer hit.

By BRIAN BERGSTEIN

When Thomas Heermann and Chris Cheung, two middle managers at the software company Autodesk, first showed off their new iPhone drawing app, they got some skeptical looks. Why would anyone want to doodle on that tiny screen? And what could a $2.99 app matter to a company with around $2 billion in annual revenue?

Two years later, Autodesk's SketchBook apps for phones and the iPad are best-sellers that have been downloaded seven million times. It doesn't add up to a huge amount of revenue: perhaps $15 million. But there's more than money to this innovation story. With its first consumer hit, Autodesk now has more customers than it did in all its previous 29 years combined.

"It's the best advertising we've had in years," says Autodesk CEO Carl Bass. What's more, the home-grown apps are teaching

Autodesk how to reach a fast-growing new audience that uses tablets and phones. Last year it launched a new consumer products division, which includes SketchBook and other design programs that don't require users to have high-end computers.

The apps' origins are a reminder that big companies can innovate too, although not necessarily in predictable ways. "You can't institutionalize innovation. If you could, everyone would do it," says Bass. He acknowledges that he probably wouldn't have put resources toward the app project—"But guess what? Two guys did it and didn't ask anyone's permission."

When Cheung, an Autodesk product manager, and Heermann, his boss, assumed responsibility for SketchBook in 2008, it was a paint-and-sketch program for PCs and a sideline for Autodesk, which is best known for its high-powered AutoCAD software that architects and engineers use. At around $100, SketchBook's price tag didn't generate much interest among resellers, either. The workaday task facing Cheung and Heermann, based at a Toronto office far from the company's headquarters in San Rafael, California, was to launch the next regular update of the program for PCs.

But Apple had launched the iPhone the previous year, and Cheung wondered whether SketchBook could work on it. With Heermann's assent, he asked developers to explore that question. Meanwhile, small companies released doodling apps for the iPhone, resolving the doubts that anyone would want to sketch on its screen.

Still, the project remained low-key: though Cheung and Heermann had to involve Autodesk's tax, legal, and finance teams before they could release SketchBook to Apple's online App Store, they never made a formal presentation to top management. Heermann says Bass saw the app only once before it was released, when Heermann showed it to him in passing, in a hallway. The CEO said, "Cool—I like it."

When the SketchBook app finally came out in September 2009, Cheung, 40, and Heermann, 47, hoped to get 100,000 downloads in a year. They got one million in 50 days. Suddenly aware of the possibilities, they moved fast to make an iPad version and had it available the day the devices went on sale in April 2010.

Heermann thinks the timing of the apps may have proved critical, because consumer-style products are beginning to gain popularity in the corporate workforce, a phenomenon known as consumerization. That shift could spell trouble for companies that are slow to adapt. Now that Autodesk is a top-ranked app seller, says Heermann, who is today the company's director of consumer products, "it's almost like having the company shape up and get ready for the future." BI

EMERGED TECHNOLOGIES

The Trouble with India's People's Car

Tata created the world's least expensive automobile. The only problem now is selling it.

By MAHENDRA RAMSINGHANI

Ratan Tata, head of the 143-year-old Indian conglomerate that bears his family name, is known as a passionate innovator so committed to risk-taking in his $83 billion empire that he gives an annual award for the "best failed idea." But that prize could go to Tata himself for one of his own dream projects: the Nano car.

The launch of the Tata Nano in 2009 was hailed as a milestone in automotive history. At 123,000 rupees, or $2,400, the Nano was dubbed "the world's cheapest car" and called a flagship example of Tata's idea of frugal innovation. It illustrated how engineering could be used to open markets in a country where per capita income is around $1,000 a year.

At first, Tata's "people's car" looked as if it could be India's Model T. Where Ford had used assembly-line innovations to create the first mass-market car, the Nano would push affordability to an extreme. Tata's engineering team introduced a lightweight hollow steering column and tore up plans for the car's floor 10 times. Smaller tires were designed using less rubber, and the wheels have three lug nuts instead of four. According to the market research firm Frost and Sullivan, the German auto supplier Bosch stripped out as many as 700 of the 1,000 functions of its electronic fuel injection and engine controls to develop cheaper versions for the Nano. All told, Tata filed around 35 patents on the technology that went in to the car's design.

When the Nano was unveiled, accolades rolled in, including the Frost and Sullivan Innovation Award. Analysts predicted that the vehicle would increase by a staggering 65 percent the number of Indian families able to own a car.

Instead, the Nano has become a hard lesson in marketing to the bottom of the economic pyramid. Just 70,432 of the cars were sold during the fiscal year ending in March. At first, some target customers were intimidated by Tata's glittering showrooms (about half of Nano buyers had never owned a car before). Others apparently just didn't like the idea of purchasing the world's cheapest car. In a country where incomes have doubled in the past five years, the Nano is seen as a glorified version of a tuk-tuk, the three-wheeled motorized rickshaw often

CHEAP WHEELS The no-frills Nano weighs 1,300 pounds and has a two-cylinder, 624cc engine. Sales of the $2,400 automobile, dubbed "the world's cheapest car," have been disappointing.

AP PHOTO/AJIT SOLANKI

seen on the streets of developing nations. Many consumers stretched their budgets to buy the Maruti-Suzuki Alto, which has a bigger 800cc engine.

Tata may have misjudged the market by offering too little with its people's car. "If you start with a very basic product, soon the customer wants more," says David Cole, chairman emeritus of the Center for Automotive Research, a nonprofit automotive-industry research group. "To precisely hit the market when you are pioneering a segment is difficult."

Tata says it is "confident" in the Nano but has been revamping its marketing plans. Ratan Tata himself went out to meet with dealers, and executives even struck a deal to display cars at Big Bazaar, a chain of retail discount stores where one can buy plastic buckets and curry powder. So far, sales continue to be choppy and are falling well short of Tata's goal of 20,000 cars per month.

One answer could be more technology. Tata has diesel and electric versions of the Nano on the drawing board, although Cole wonders if such strategies will work. "If the market is soft, you cannot solve market problems by adding technology features," he says. "Hybrid or diesel versions can potentially double the costs of Nano—a very risky step."

Tata continues to push ahead with frugal innovation, including a $700 prefabricated home and a low-cost water filter called Swach. One idea that didn't make it was an inexpensive all-plastic door designed for the Nano. But it was a good effort. The door was a nominee for the "Dare to Try" award—the one for the best failed idea. BI

MAHENDRA RAMSINGHANI IS THE AUTHOR OF *THE BUSINESS OF VENTURE CAPITAL* AND MANAGES INVEST DETROIT'S FIRST STEP FUND.

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reviews

ECONOMICS

"Tectonic Shifts" in Employment

Information technology is reducing the need for certain jobs faster than new ones are being created.

By DAVID TALBOT

The United States faces a protracted unemployment crisis: 6.3 million fewer Americans have jobs than was true at the end of 2007. And yet the country's economic output is higher today than it was before the financial crisis. Where did the jobs go? Several factors, including outsourcing, help explain the state of the labor market, but fast-advancing, IT-driven automation might be playing the biggest role.

Since the beginning of the Industrial Revolution, people have feared that new technologies would permanently erode employment. Over and over again, these dislocations of labor have been temporary: technologies that made some jobs obsolete eventually led to new kinds of work, raising productivity and prosperity with no overall negative effect on employment.

There's nothing to suggest that this dynamic no longer operates, but new research is showing that advances in workplace automation are being deployed at a faster pace than ever, making it more difficult for workers to adapt and wreaking havoc on the middle class: the clerks, accountants, and production-line workers whose tasks can increasingly be mastered by software and robots. "Do I think we will have permanently high unemployment as a consequence of technology? No," says Peter Diamond, the MIT economist who won a 2010 Nobel Prize for his work on market imperfections, including those that affect employment. "What's different now is that the nature of jobs going away has changed. Communication and computer abilities mean that the type of jobs affected have moved up the income distribution."

Race Against the Machine: How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy
Erik Brynjolfsson and Andrew McAfee
October 2011

"The Growth of Low Skill Service Jobs and the Polarization of the U.S. Labor Market"
David Autor and David Dorn
June 2011

Erik Brynjolfsson and Andrew McAfee study information-supercharged workplaces and the innovations and productivity advances they continually create. Now they have turned their sights to how these IT-driven improvements affect employment. In their new book, Brynjolfsson, director of the Center for Digital Business at MIT's Sloan School of Management, and McAfee, its principal research scientist, see a paradox in the first decade of the 2000s. Even before the economic downturn caused U.S. unemployment to rise from 4.4 percent in May 2007 to 10.1 percent in October 2009, a disturbing trend was visible. From 2000 to 2007, GDP and productivity rose faster than they had in any decade since the 1960s, but employment growth was comparatively tepid.

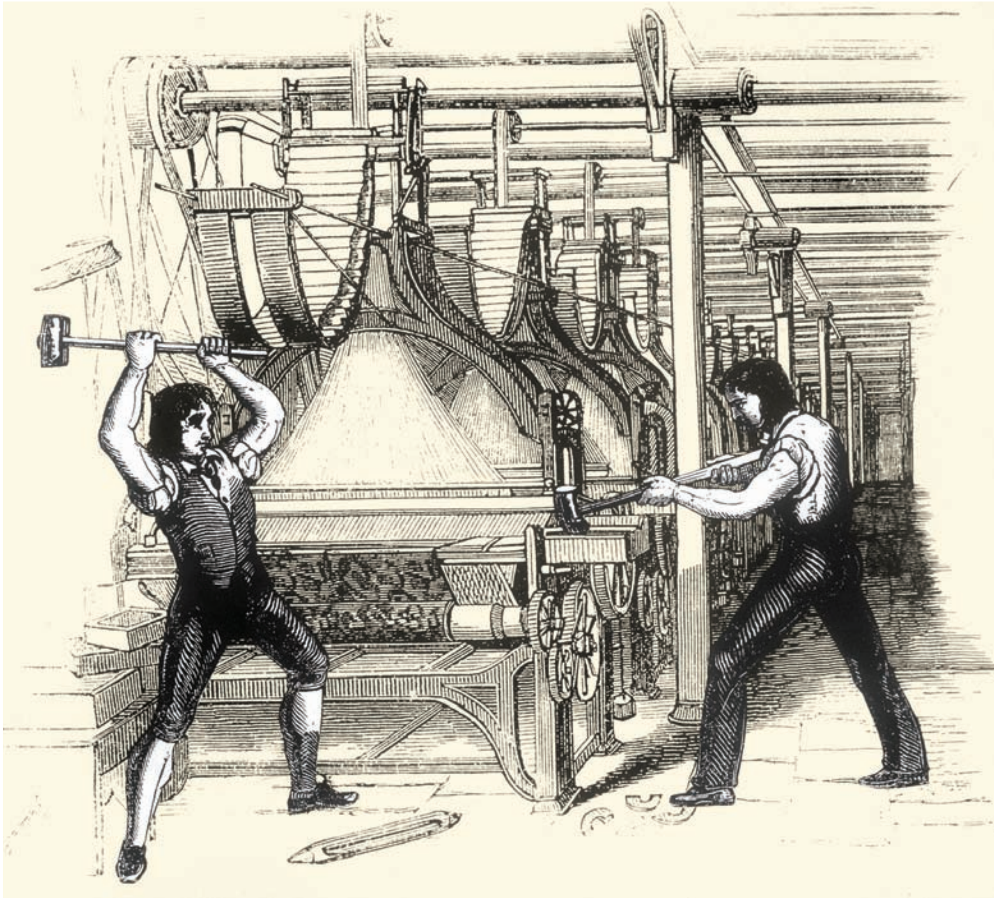
Brynjolfsson and McAfee posit that more work was being done by, or with help from, machines. For example, Amazon.com reduced the need for retail staffers; computerized kiosks in hotels and airports replaced clerks; voice-recognition and speech systems replaced customer support staff and operators; and businesses of all kinds took advantage of tools such as enterprise resource planning software. "A classically trained economist would say: 'This just means there's a big adjustment taking place until we find the new equilibrium—the new stuff for people to do,'" says McAfee.

We've certainly made such adjustments before. But whereas agricultural advances played out over a century and electrification and factory automation rolled out over decades, the power of some information technologies is essentially doubling every two years or so as a consequence of Moore's Law. It took some time for IT to fully replace the paper-driven workflows in cubicles, management suites, and retail stores. (In the 1980s and early 1990s productivity grew slowly, and then it took off after 1996; some economists explained that IT was finally being used effectively.) But now, Brynjolfsson and McAfee argue, the efficiencies and automation opportunities made possible by IT are advancing too fast for the labor market to keep up.

More evidence that technology has reduced the number of good jobs can be

found in a working paper by David Autor, an economist at MIT, and David Dorn, an economist at the Center for Monetary and Financial Studies in Madrid. They too point to the crucial years of 2000–2005. Job growth happened mainly at the ends of the spectrum: in lower-paying positions, in areas such as personal care, cleaning services, and security, and in higher-end professional positions for technicians, managers, and the like. For laborers, administrative assistants, production workers, and sales representatives, the job market didn't grow as fast—or even shrank. Subsequent research showed that things got worse after 2007. During the recession, nearly all the nation's job losses were in those middle categories—the positions easiest to replace, fully or in part, by technology.

Brynjolfsson says the trends are "troubling." And they are global; some of the jobs that IT threatens, for example, are at electronics factories in China and transcription services in India. "This is not about replacing all work, but rather about tectonic shifts that have left millions much worse off and others much better off," he says. While he doesn't believe the problem is permanent, that's of little solace to the millions out of work now, and they may not be paid at their old rates even when they do find new jobs. "Over the longer term, they will develop new skills, or entrepreneurs will figure out ways of making use of their skills, or wages will drop, or all three of those things will happen," he says. "But in the short run, your old set of skills that created a lot of value are not useful anymore."



A JOB TO DO Much as the Luddites feared mechanical looms 200 years ago, today's middle-class workers have reason to worry that information technology erodes their employment prospects.

MARY EVANS PICTURE LIBRARY/ALAMY

This means there's a risk, unless the economy generates new high-quality jobs, that the people in the middle will face the prospect of menial jobs—whose wages will actually decline as more people compete for them. "Theory says the labor market will 'clear.' There are always things for people to do," Autor says. "But it doesn't say at what price." And even as it gets crowded and potentially even less rewarding at the bottom, employees at the top are getting paid more, thanks to the multiplier effects of technology. Some 60 percent of the income growth in the United States between 2002 and 2007 went to the top 1 percent of Americans—the bulk of whom are executives whose companies are getting richer by using IT to become more efficient, Brynjolfsson and McAfee point out.

Dramatic shifts have happened before. In 1800, 90 percent of Americans were employed in agriculture. The figure was down to 41 percent by 1900 and stands at 2 percent today. People work, instead, in new industries that were unimaginable in the early 19th century. Such a transformation could happen again. Today's information technologies, even as they may do short-term harm to some kinds of employees, are clearly a boon to entrepreneurs, who now have cheaper and more powerful tools at their disposal than at any other time in history. As jobs are lost, Brynjolfsson says, "we will be running an experiment on the economy to see if entrepreneurs invent new ways to be productive equally quickly." As examples, he points to eBay and Amazon Marketplace, which together allow hundreds of thousands of people to make their living hawking items to customers around the world.

The problem, he says, is that not enough people are sufficiently educated or technologically savvy to exploit such rapid advances and develop as-yet-unimagined entrepreneurial niches. He and McAfee

conclude their book by arguing that the same technologies now making industry far more productive should be applied to updating and improving the educational system. (In one promising example they cite, 58,000 people went online to take an artificial-intelligence class offered by Stanford University.)

IT-based entrepreneurship isn't the only potential technological driver of new jobs. Revitalizing manufacturing *(see "Can We Build Tomorrow's Breakthroughs?" p. 36)* could also help. But automation has made manufacturing far less labor intensive, so even a manufacturing revival is not likely to mean a great many new jobs on balance. Likewise, anyone whose hopes are pinned on "green jobs" may be disappointed. Though jobs will be created in the switch to cleaner energy sources, jobs tied to traditional energy will be lost in the same process. Many economists are not certain what the net effect will be. And in any case, these days manufacturing and energy account for small slices of the U.S. economy, which is now driven much more by the service sector. That's why fast-advancing information technologies, with their pervasive reach and their potential to create new services and satisfy new niche markets, may be a better bet for job creation—though the tumult IT is causing in the labor market isn't necessarily going to resolve itself quickly.

Peter Diamond says that one of the most important things the government can do for employment is to take care of basics, like infrastructure and education. "As long as we have so many idle resources, this is the time when it's advantageous—and socially less expensive—to engage in public investment," he says. Eventually, he believes, the economy will adapt and things will work out, once again. "Jobs have been changing and moving around—within the country, out of the country—for a very long time," he says. "There will be other kinds of jobs that still require people." tr

DAVID TALBOT IS *TR*'S CHIEF CORRESPONDENT.

MEDICINE

Technological Healing

A leading researcher says digital technologies are about to make health care more effective. But is so much data really beneficial?

By SHARON BEGLEY

Nanosensors patrolling your bloodstream for the first sign of an imminent stroke or heart attack, releasing anticlotting or anti-inflammatory drugs to stop it in its tracks. Cell phones that display your vital signs and take ultrasound images of your heart or abdomen. Genetic scans of malignant cells that match your cancer to the most effective treatment.

In cardiologist Eric Topol's vision, medicine is on the verge of an overhaul akin to the one that digital technology has brought to everything from how we communicate to how we locate a pizza parlor. Until now, he writes in his upcoming book *The Creative Destruction of Medicine: How the Digital Revolution Will Create Better Health Care,* the "ossified" and "sclerotic" nature of medicine has left health "largely unaffected, insulated, and almost compartmentalized from [the] digital revolution." But that, he argues, is about to change.

The Creative Destruction of Medicine: How the Digital Revolution Will Create Better Health Care
by Eric Topol
Basic Books, 2012

Digital technologies, he foresees, can bring us true prevention (courtesy of those nanosensors that stop an incipient heart attack), individualized care (thanks to DNA analyses that match patients to effective drugs), cost savings (by giving patients only those drugs that help them), and a reduction in medical errors (because of electronic health records, or EHRs). Virtual house calls and remote monitoring could replace most doctor visits and even many hospitalizations. Topol, the director of the Scripps Translational Science Institute, is far from alone: e-health is so widely favored that the 2010 U.S. health-care reform act allocates billions of dollars to electronic health records in the belief that they will improve care.

Anyone who has ever been sick or who is likely to ever get sick—in other words, all of us—would say, Bring it on. There is only one problem: the paucity of evidence that these technologies benefit patients. Topol is not unaware of that. The eminently readable *Creative Destruction* almost seems to have two authors, one of them a rigorous, hard-nosed physician/researcher who insightfully critiques the tendency to base treatments on what is effective for the average patient. This Topol cites study after study showing that much of what he celebrates may not benefit many individual patients at all. The other author, however, is a kid in the electronics store whose eyes light up at every cool new toy. He seems to dismiss the other Topol as a skunk at a picnic.

Much of the enthusiasm for bringing the information revolution to medicine reflects the assumption that more information means better health care. Actual data offer reasons for caution, if not skepticism. Take telemonitoring, in which today's mobile apps and tomorrow's nanosensors would measure blood pressure, respiration, blood glucose, cholesterol, and other physiological indicators. "Previously, we've been able to assess people's health status when they came in to a doctor's office, but mobile and wireless technology allow us to monitor and track important health indicators throughout the day, and get alerts before something gets too bad," says William Riley, program director at the National Heart, Lung & Blood Institute and chairman of a mobile health interest group at the National Institutes of Health. "Soon there won't be much that we can't monitor remotely."

MORE DATA Technologies aimed at improving our health are proliferating. One example is this device that plugs into an iPhone to turn it into a glucose monitor.

PATRIK STOLLARZ/AFP/GETTY IMAGES

Certainly, it is worthwhile to monitor blood pressure, glucose, and other indicators; if nothing else, having regular access to such data might help people make better choices about their health. But does turning the flow of data into a deluge lead to better results on a large scale? The evidence is mixed. In a 2010 study of 480 patients, telemonitoring of hypertension led to larger reductions in blood pressure than did standard care. And a 2008 study found that using messaging devices and occasional teleconferencing to monitor patients with chronic conditions such as diabetes and heart disease reduced hospital admissions by 19 percent. But a 2010 study of 1,653 patients hospitalized for heart failure concluded that "telemonitoring did not improve outcomes." Similarly, a recent review of randomized studies of mobile apps for smoking cessation found that they helped in the short term, but that there is insufficient research to determine the long-term benefits. Given the land rush into mobile health technologies, or "m-health," the lack of data on their helpfulness raises concerns. "People are putting out systems and technologies that haven't been studied," says Riley.

These concerns also apply to technologies we don't have yet, like those nanosensors in our blood. For instance, studies have reached conflicting conclusions about whether diabetics benefit from aggressive glucose control—something that could be provided by nanosensors paired with insulin delivery devices. Several studies have found that it can lead to hypoglycemia (dangerously low levels of blood glucose) and does not reduce mortality in severely ill diabetics. And sensors may be no better at detecting incipient cancers or heart attacks. If the ongoing debate about overdiagnosis of breast and prostate cancer has taught us anything, it should be that an abnormality that looks like cancer might not spread or do harm, and therefore should not necessarily be treated. For heart attacks, we need rigorous clinical trials establishing the rate of false positives and false negatives before we start handing out nanosensors like lollipops.

EHRs also seem like a can't-miss advance: corral a patient's history in easily searched electrons, rather than leaving it scattered in piles of paper with illegible scribbles, and you'll reduce medical errors, minimize redundant tests, avoid dangerous drug interactions (the system alerts the prescriber if a new prescription should not be taken with an existing one), and ensure that necessary exams are done (by reminding a physician to, say, test a diabetic's vision).

In practice, however, the track record is mixed. In one widely cited study, scientists led by Jeffrey Linder of Harvard Medical School reported in 2007 that EHRs were not associated with better care in doctor's offices on 14 of 17 quality indicators, including managing common diseases, providing preventive counseling and screening tests, and avoiding potentially inappropriate prescriptions to elderly patients. (Practices that used EHRs did do better at avoiding unnecessary urinalysis tests.) Topol acknowledges that there is no evidence that the use of EHRs reduces diagnostic errors, and he cites several studies that, for instance, found "no consistent association between better quality of care and [EHRs]." Indeed, one disturbing study he describes showed that the rate of patient deaths doubled in the first five months after a hospital computerized its system for ordering drugs.

Financial incentives threaten another piece of Topol's vision. Perhaps the most promising path to personal medicine is pharmacogenomics, or using genetics to identify patients who will—or will not—benefit from a drug. Clearly, the need is huge. Clinical trials have shown that only one or two people out of 100 without prior heart disease benefit from a certain statin, for instance, and one heart attack victim in 100 benefits more from tPA (tissue plasminogen activator, a genetically engineered clot-dissolving drug) than from streptokinase (a cheap, older clot buster). Genetic scans might eventually reveal who those one or two are. Similarly, as Topol notes, only half the patients receiving a $50,000 hepatitis C drug, and half of those taking rheumatoid arthritis drugs that ring up some $14 billion in annual sales, see their health improve on these medications. By preëmptively identifying who's in which half, genomics might keep patients, private insurers, and Medicare from wasting tens of billions of dollars a year.

Yet despite some progress in matching cancer drugs to tumors, pharmacogenomics "has had limited impact on clinical practice," says Joshua Cohen of the Tufts Center for the Study of Drug Development, who led a 2011 study of the field. Several dozen diagnostics are in use to assess whether patients would benefit from a specific drug, he estimates; one of the best-known analyzes breast cancers to see if they are fueled by a mutation in the her2 protein, which means they are treatable with Herceptin. But insurers still doubt the value of most such tests. It's not clear that testing everyone who's about to be prescribed a drug would save money com-

pared with giving it to all those patients and letting the chips fall where they may.

Genotyping is not even routine in clinical trials of experimental cancer drugs. As Tyler Jacks, an MIT cancer researcher, recently told me, companies "run big dumb trials" rather than test drugs specifically on patients whose cancer is driven by the mutation the drug targets. Why? Companies calculate that it is more profitable to test these drugs on many patients, not just those with the mutation in question. That's because although a new drug might help nearly all lung cancer patients with a particular mutation, a research trial might indicate that it helps—just to make up a number—30 percent of lung cancer patients as a whole. Even that less impressive number could be enough for Food and Drug Administration approval to sell the drug to everyone with lung cancer. Limiting the trial to those with the mutation would limit sales to those patients. The risk that the clinical trial will fail is more than balanced by the chance to sell the drug to millions more people.

Such financial considerations are not all that stands in the way of Topol's predictions. He and other enthusiasts need to overcome the lack of evidence that cool gadgets will improve health and save money. But though he acknowledges the "legitimate worry" about adopting technologies before they have been validated, his cheerleading hardly flags. "The ability to digitize any individual's biology, physiology, and anatomy" will "undoubtedly reshape" medicine, he declares, thanks to the "super-convergence of DNA sequencing, mobile smart phones and digital devices, wearable nanosensors, the Internet, [and] cloud computing." Only a fool wouldn't root for such changes, and indeed, that's why Topol wrote the book, he says: to inspire people to demand that medicine enter the 21st century. Yet he may have underestimated how much "destruction" will be required for that goal to be realized. tr

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WEB

The Law of Online Sharing

Facebook's Mark Zuckerberg will eventually have to deal with the fact that all growth has limits.

By PAUL BOUTIN

The idea of limitless growth gives sleepless nights to environmentalists, but not to Facebook founder Mark Zuckerberg. He espouses a law of social sharing, which predicts that every year, for the foreseeable future, the amount of information you share on the Web will double.

That rule of thumb can be visualized mathematically as a rapidly growing exponential curve. More simply, our online social lives are set to get significantly busier. As for Facebook, more personal data means better ad targeting. If things work out, Zuckerberg's net worth will follow a similar trajectory to that described in his law of social sharing.

That law is said to be mathematically derived from data inside Facebook. In ambition, it is closely modeled on Moore's Law, which was conceived by the computer-processor pioneer Gordon Moore in 1965 and has been at work in every advance in computing since. Also an exponential curve, it states that every two years twice as many transistors can be fitted onto a chip of any given area for the same price, allowing processing power to get cheaper and more capable.

There's a hint of vanity in Zuckerberg's attempt to ape Moore. But it makes sense to try to describe the mechanisms that have raised Facebook and other social-Web companies to power. The Web defines our time and is being rapidly reshaped by social content—from dumb viral videos to earnest pleas on serious issues. Facebook's success has left older companies like Google scrambling to add social features to their own products *(see Q&A, November/December 2011)*. Zuckerberg's Law can help us understand such a sudden change of tack from a seemingly dominant company, just as Moore's Law has long been used to plan and explain new strategies and technologies.

Inasmuch as Facebook is the company most invested in Zuckerberg's Law, its every move can be understood as an effort to sustain the graceful upward curve of its founder's formula. The short-term prospects look good for Zuckerberg. The original Moore's Law is on his side; faster, cheaper computers and mobile devices have made sharing easier and allowed us to do it wherever we go. Just as important, we are willing to play along, embracing new features from Facebook and others that lead us to share things today that we wouldn't or couldn't have yesterday.

The law of social sharing
Facebook Beacon
Facebook Open Graph
Frictionless sharing
Spotify
Blippy

Facebook's most recent major product launch, last September, is clearly aimed at validating Zuckerberg's prophecy and may provide its first real test. An upgrade to the Open Graph platform that unleashed the now ubiquitous Like button onto the Web *(see "You Are the Ad," May/June 2011)*, it added a feature that allows apps and Web sites to automatically share your activity via Facebook as you go about your business. Users must first give a service permission to share automatically on their behalf. After that, frictionless sharing, as it has become known, makes sharing happen without your needing to click a Like button, or to even think about sharing. The most prominent early implementation was the music-streaming service Spotify, which

can now automatically post on Facebook the details of every song you listen to. In the first two months of frictionless sharing, more than 1.5 billion "listens" were shared through Spotify and other music apps. News organizations like the *Washington Post* use the feature, making it possible for them to share every article a person reads on their sites or in a dedicated app. Frictionless sharing is also helping Facebook drag formerly offline activities onto the Web. An app for runners can now automatically post the time, distance, and path of a person's morning run.

Frictionless sharing sustains Zuckerberg's Law by automating what used to be a manual task, thus removing a brake on the rate at which we can share. It also shows that we are willing to compromise our previous positions on how much sharing is too much. Facebook introduced a form of automatic sharing four years ago with a feature called Beacon, but it retreated after a strong backlash from users. Beacon automatically shared purchases that Facebook members made through affiliated online retailers, such as eBay. Frictionless sharing reintroduces the same basic model with the difference that it is opt-in rather than opt-out. Carl Sjogreen, a computer scientist who is a product director overseeing Open Graph, says it hasn't elicited anything like the rage that met Beacon's debut. "Everyone has a different idea of what they want to share, and what they want to see," says Sjogreen. Moreover, judging by the number of Spotify updates from my Facebook friends, frictionless sharing is pretty popular.

Privacy concerns will surely arise again as Facebook and others become able to ingest and process more of our personal data. Yet our urge to share always seems to win out. The potential for GPS-equipped cell phones to become location trackers, should the government demand access to our data, has long concerned some people. A *South Park* episode last year even portrayed an evil caricature of Apple boss Steve Jobs standing before a wall-sized map labeled "Where Everybody in the World Is Right Now." Six months later, to a mostly positive reception, Apple debuted a new iPhone feature called Find My Friends, which encourages users to let Apple track their location and share it.

It's not hard to explain why we seem eager to do our bit to maintain the march of Zuckerberg's Law. Social sites are like Skinner boxes: we press the Like button and are rewarded with attention and interaction from our friends. It doesn't take long to get conditioned to that reward. Frictionless sharing can now push the lever for us day and night, in hopes of drawing even more attention from others.

Unfortunately for Zuckerberg and his law, not every part of that feedback loop can be so easily boosted. Frictionless sharing helps, but getting others to care is the bigger challenge. In 2009 a new social site called Blippy was launched; it connected with your credit card to create a Twitter-style online feed of everything you bought. That stream could be made public or shared with particular contacts. Blippy got a lot of press but not the wide adoption its cofounder Philip Kaplan had hoped for. "Most people thought Blippy's biggest challenge would be getting users to share their purchases," he says. "Turns out the hard part was getting users to look at other people's purchases. Getting people to share is a small hump. Getting them to obsess over the data—making it fun, interesting, or useful—is the big hump."

Sjogreen has that problem in his sights. He says he is working on ways to turn the impending flood of daily trivialities coming from frictionless sharing into something fun, interesting, and useful. Repackaging the raw information to make it more compelling to others is one tactic. "It's the patterns and anomalies that matter to us," he says. For example, if you notice that a friend just watched 23 episodes of *Breaking Bad* in a row, you may decide you should check out that show after all. Or if he sets a new personal record on his morning run, the app in the phone strapped to his arm could automatically tout it to friends. Perhaps Blippy would have thrived if it highlighted significant purchases like vacations, instead of simply blasting people with everything from grocery lists to fuel bills.

We can only guess at the effectiveness of Sjogreen's future tactics, but it is certain that they can sustain Zuckerberg's Law for only so long. Gordon Moore put it well in 2005 when reflecting on the success of his own law: "It can't continue forever. The nature of exponentials is that you push them out and eventually disaster happens."

Facebook's impending problem is that even if the company enables future pacemakers to share our every heartbeat, the company cannot automate caring—the most important part of the feedback loop that has driven the social Web's ascent. Nothing can support exponential growth for long. No matter how cleverly our friends' social output is summarized and highlighted for us, there are only so many hours in the day for us to express that we care. Today, the law of social sharing is a useful way to think about the rise of social computing, but eventually, reality will make it obsolete. tr

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hack

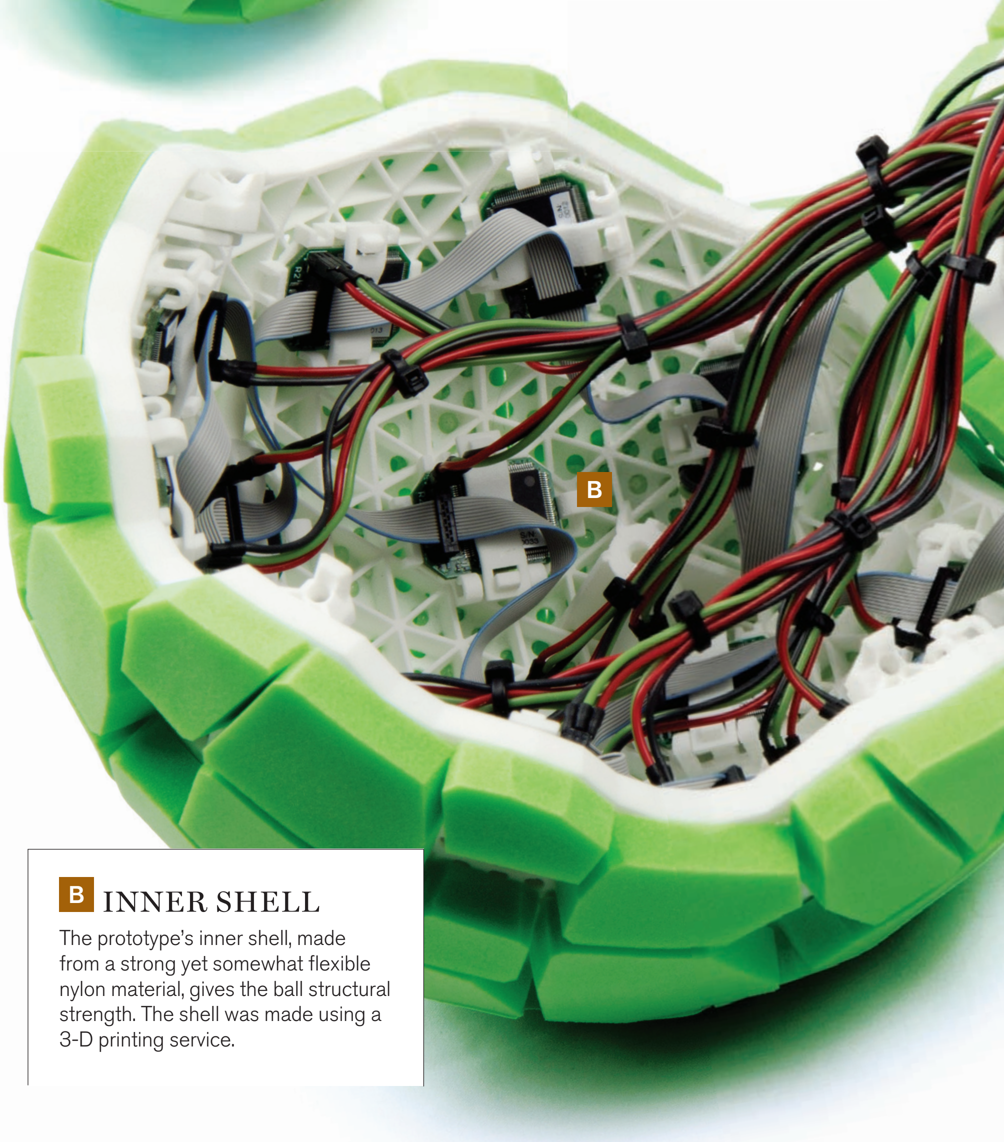
Eye Ball

A globe studded with cameras captures a panorama if you throw it in the air.

By STEPHEN CASS

A OUTER SHELL

The sphere, about the size of a softball, is protected by blocks of foam. Thirty-six cell-phone camera modules, each with a resolution of two megapixels, are set into the surface. Each module stores its portion of the mosaic until it is transferred to the ball's microcontroller.

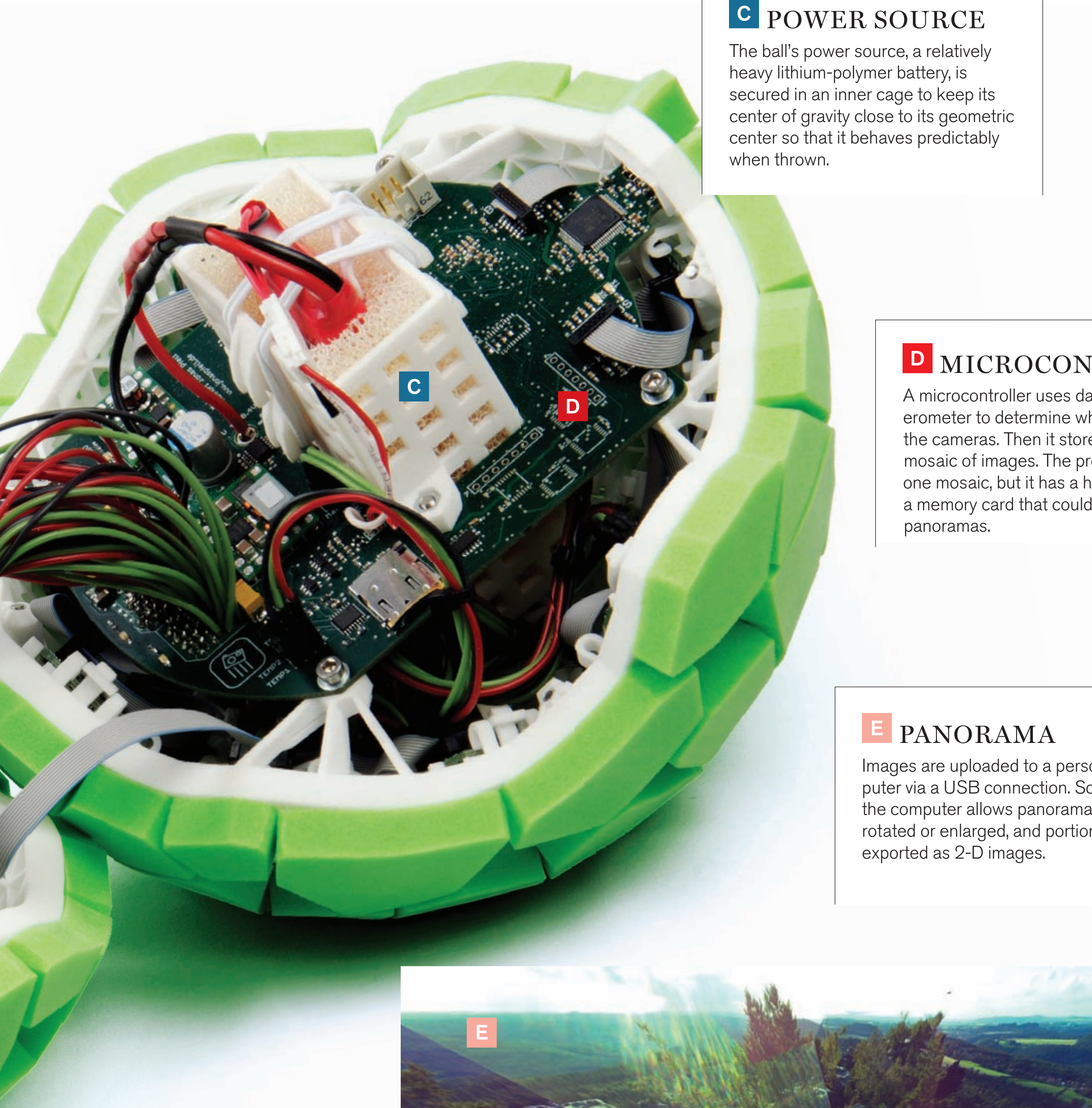


B INNER SHELL

The prototype's inner shell, made from a strong yet somewhat flexible nylon material, gives the ball structural strength. The shell was made using a 3-D printing service.

IF YOU TOSS this foam-covered ball skyward, an accelerometer inside determines when it has reached its maximum height. At that moment, 36 cameras are triggered simultaneously, creating a mosaic that can be downloaded and viewed on a computer as one spherical panoramic image. The ball was created by researchers at the Technische Universität Berlin after one of them, Jonas Pfeil, labored to create panoramas while on vacation in Tonga. On that trip, he tried a cumbersome process that required snapping pictures in different directions and stitching them together later in a photo-editing program. Now he hopes to license the camera-ball technology for commercial production.

www See a video showing the ball camera in operation: **technologyreview.com/hack**



C POWER SOURCE

The ball's power source, a relatively heavy lithium-polymer battery, is secured in an inner cage to keep its center of gravity close to its geometric center so that it behaves predictably when thrown.

D MICROCONTROLLER

A microcontroller uses data from an accelerometer to determine when to trigger the cameras. Then it stores the resulting mosaic of images. The prototype can store one mosaic, but it has a hardware slot for a memory card that could store additional panoramas.

E PANORAMA

Images are uploaded to a personal computer via a USB connection. Software on the computer allows panoramas to be rotated or enlarged, and portions can be exported as 2-D images.

QIAN QIN (MAIN PHOTO); JONAS PFEIL

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Nanotech Goes Big

Large sheets made from carbon nanotubes could lead to lighter aircraft and more resilient space probes.

By KATHERINE BOURZAC

At a small factory in Concord, New Hampshire, workers at the startup Nanocomp Technologies are turning carbon nanotubes into paper-thin sheets many meters long. The nanotubes, which are each just a few billionths of a meter wide, are among the strongest and most conductive materials known. For decades researchers have dreamed of using them to make super-efficient electrical transmission lines, suspension bridges that can span several kilometers, and even elevators that convey satellites into space. But while some companies have succeeded in making useful products by mixing nanotubes with resins to create composites, it's been difficult to make materials with properties that reflect those of the individual nanotubes. By making large sheets composed of nanotubes alone, Nanocomp has taken a big step in that direction.

The sheets are still not as strong or conductive as individual nanotubes, but they can provide a lighter replacement for copper and other conventional materials in some applications, including protective shielding for coaxial cables. Nanocomp's first customers are NASA, which has used nanotube sheets to shield a deep-space probe from radiation, and the U.S. military,

PORTER GIFFORD

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which could use the sheets to reduce the weight of the electrical cables on unmanned drones by half, increasing flight times.

Nanotubes are made by feeding alcohol and a catalyst into a furnace at high temperatures and pressures. Nanocomp has fine-tuned the process to produce relatively long nanotubes that emerge from the furnace to form networks that can serve as the basis for sheets. Practical large-scale manufacturing is the critical first step to futuristic applications, says John Dorr, the company's vice president of business development. That will get nanotube products out of the lab and to the market at competitive prices. tr

1. This mixture of alcohol and an iron catalyst, which makes the solution yellow, is fed into Nanocomp's furnaces at high temperature and pressure. The action of the catalyst and the extreme conditions inside the furnace cause the carbon atoms in the alcohol to bind together to form long nanotubes.

2. Pure nanotubes billow out of the furnace, which is operating in excess of 1,000 °C. As they emerge, they tangle together, forming networks that will be key to the strength of the finished sheets.

3. The tangled nanotubes accumulate on the surface of the spinning roller at the upper right of the picture.

4. Nanocomp runs this process continuously for 18 hours to make a two-meter-square sheet of loosely packed nanotubes, shown here.

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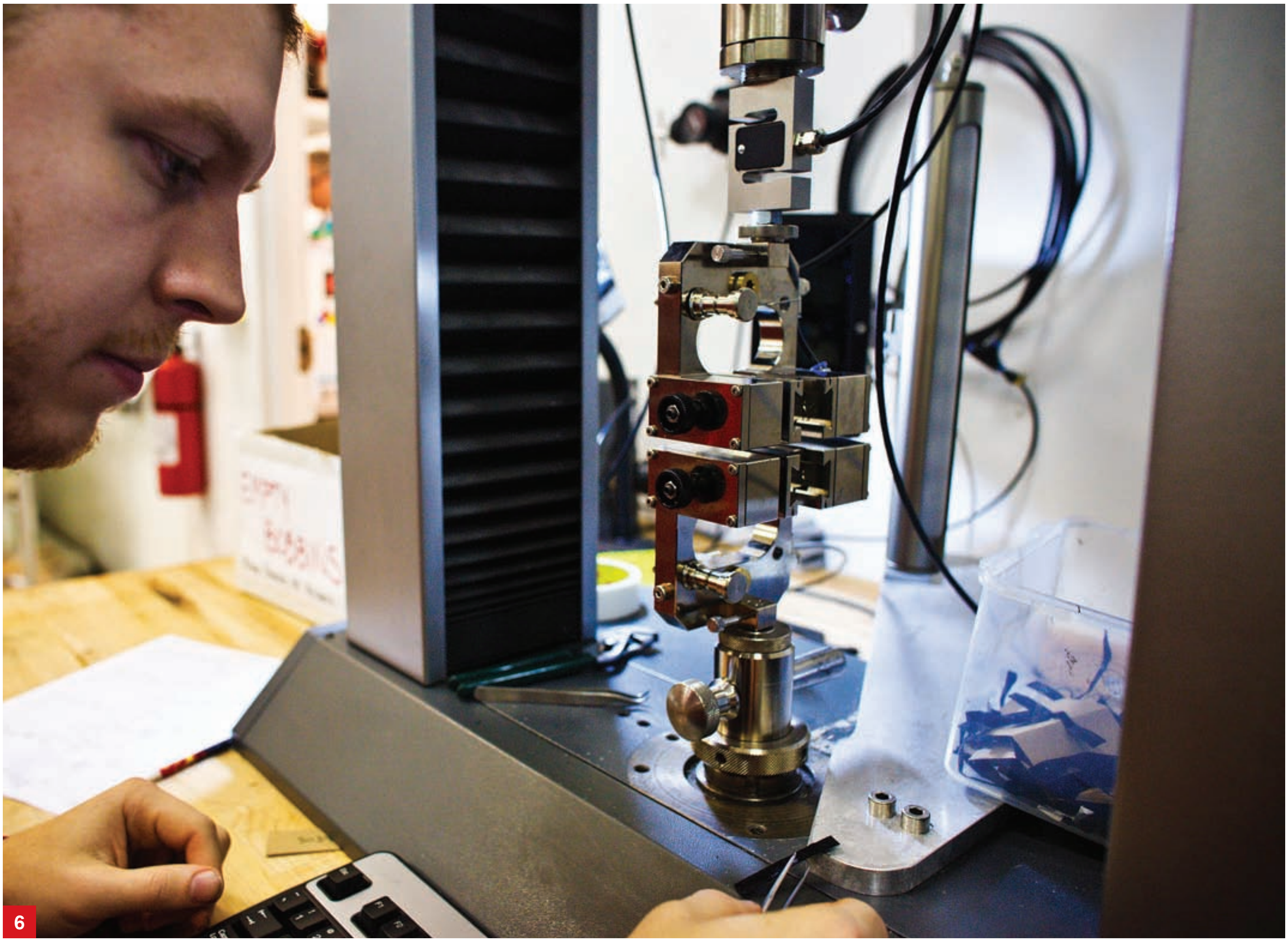

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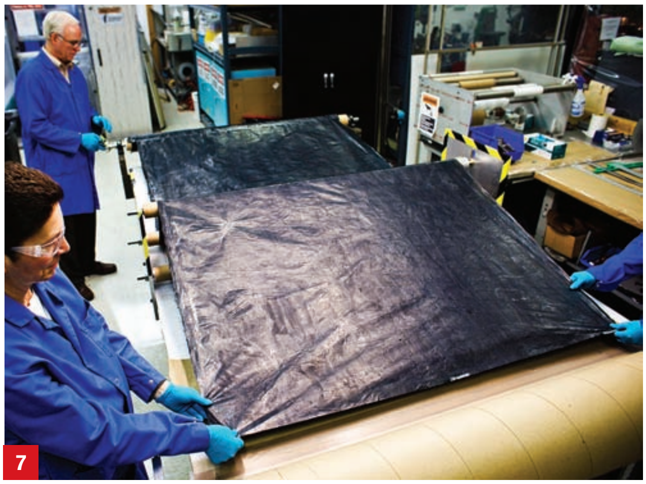

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5. A worker sprays the nanotube sheet with strong acid. As the acid dries, capillary forces pull the nanotubes together, compressing the sheet to form a dense, shiny mat of closely connected tubes. The acid treatment makes the sheet stronger and more conductive.

6. Before the completed sheets are sent out to Nanocomp's customers, the company tests their quality. Here a worker places a small piece of a sheet between two clamps, which will pull on it to test its tensile strength. The sheets are almost as strong as steel.

7. Workers glue sheets together with an industrial adhesive, then roll them up and ship them to customers. This roll is 61 meters long. The company's customers use the sheets as a layer in composite materials or to protect signals sent along coaxial cables from electromagnetic interference, among other applications.

PORTER GIFFORD; IMAGE 5 COURTESY OF NANOCOMP TECHNOLOGIES

from the labs

ENERGY

Power Polymers

Conductive binders could make high-capacity battery electrodes practical

SOURCE: "POLYMERS WITH TAILORED ELECTRONIC STRUCTURE FOR HIGH CAPACITY LITHIUM BATTERY ELECTRODES"
Gao Liu et al.
Advanced Materials, published online September 23, 2011

RESULTS: An electrode material that combines silicon with a new polymer developed by researchers at Lawrence Berkeley National Laboratory can store four times as much energy as conventional anodes, potentially increasing overall battery storage by 30 percent. The electrodes maintained these performance levels over 650 charging cycles.

WHY IT MATTERS: Silicon electrodes have a high theoretical storage capacity, but they tend to break up after only a few charges, greatly reducing their actual capacity. Using silicon in the shape of nanowires and other nanostructures helps, but that makes it difficult to maintain electrical conductivity, and the manufacturing techniques required could prove expensive. The new polymer holds silicon particles together and maintains conductivity, and electrodes made with it could be produced on existing battery manufacturing equipment. The resulting higher-capacity batteries could improve personal electronics and extend the range of electric vehicles.

METHODS: The researchers analyzed the voltage levels and other conditions that materials encounter in battery electrodes and worked with theoretical chemists to identify a list of conductive polymers that could withstand these conditions. They added molecules designed to tune the electrical properties of the polymer and to make it more flexible, which in turn improves its ability to bind particles of silicon together.

NEXT STEPS: The researchers are collaborating with a major material-industry partner to scale up production of silicon-based electrodes that use the binders.

MATERIALS

Nanotube Motor

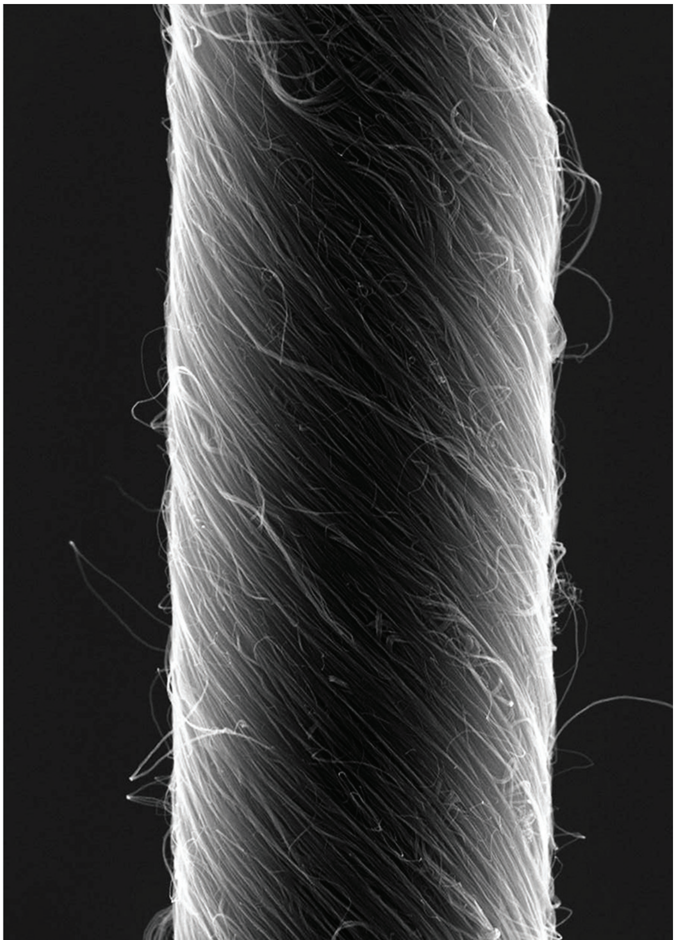
Artificial muscles could power tiny actuators and microfluidic mixers

SOURCE: "TORSIONAL CARBON NANOTUBE ARTIFICIAL MUSCLES"
Ray Baughman et al.
Science 334: 494–497

RESULTS: Researchers at the University of Texas at Dallas made nanotube yarn that twists in response to electricity, enabling it to act as a motor. For a given length, it twists 1,000 times more than other materials designed for use as tiny motors, such as shape-memory alloys that change shape in response to heat or another stimulus. The fastest of the nanotube motors spins at 600 revolutions per minute and can generate as much twisting force as a conventional motor. Researchers demonstrated this ability by using it to mix fluids with a paddle.

WHY IT MATTERS: Making useful motors for very small applications has been difficult because decreasing the size of conventional motors greatly decreases the amount of twisting force they can exert relative to their weight. Even at this scale—just a fraction of a hair's width—the nanotube yarn can exert as much force relative to its weight as a large motor. It could be useful for moving fluids around in microfluidic devices.

METHODS: The researchers used previously developed



SKINNY STRENGTH This carbon nanotube yarn, which has a diameter of 3.8 micrometers, twists when connected to an electrode and immersed in conductive liquid.

COURTESY OF UT DALLAS

methods to twist carbon nanotubes together into a thin yarn. They dipped one half of the yarn, along with an electrode, in an electrolyte. They also attached a paddle to the middle of the piece of yarn and anchored both ends to prevent them from rotating. When they applied electricity, ions from the electrolyte were attracted to electrons in the nanotubes. As the ions moved into the yarn, its volume increased, causing it to partially untwist; this, in turn, made the paddle move. When the power was cut, the half of the yarn that wasn't immersed in the electrolyte acted as a spring that returned the paddle to its original position.

NEXT STEPS: The researchers are now building microfluidic circuits that use the motors as pumps and mixers. They are also starting to make robots the size of bacteria that are propelled by the nanotube yarns.

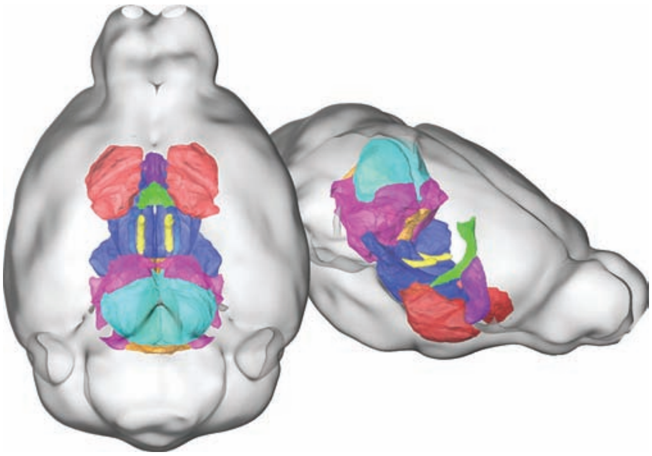
BIOMEDICINE

Mimicking Autism

Mice lacking a specific piece of DNA show symptoms like those in humans

SOURCE: "DOSAGE-DEPENDENT PHENOTYPES IN MODELS OF 16P11.2 LESIONS FOUND IN AUTISM"
Alea A. Mills, Michael Wigler, et al.
Proceedings of the National Academy of Sciences 108: 17076–17081

RESULTS: Scientists engineered mice whose DNA had deletions or duplications at



PNAS

BRAIN GENES This MRI scan of a mouse brain highlights the areas affected by chromosomal variations linked to autism.

a specific site that has previously been linked to autism and schizophrenia. Animals in which this chromosome section was missing showed behaviors associated with autism, such as repetitive movements and sleep problems. In contrast, mice with an extra copy of this region slept more. Those with the deletion also had a larger hypothalamus, the part of the brain that controls eating and sleep.

WHY IT MATTERS: The animals with the deletion will help scientists study the effects of this abnormality on all stages of brain development, which could in turn shed light on neurological deficits underlying autism. Researchers also hope to find early biomarkers of autism that could be used to help diagnose the disorder.

METHODS: The researchers used chromosome engineering to create mice with the deletion or duplication on chromosome 16. To precisely track the animals' movement, they used an infrared camera system. MRI scans were used to determine the volume of different parts of the brain.

NEXT STEPS: The section of chromosome 16 under study includes 27 genes. In order to identify the genes responsible for the autism-like features, the researchers plan to create mice with missing or extra copies of different subsections of this chromosome segment.

Predicting Response to Cancer Treatment

A new test could make chemotherapy more effective

SOURCE: "PRETREATMENT MITOCHONDRIAL PRIMING CORRELATES WITH CLINICAL RESPONSE TO CYTOTOXIC CHEMOTHERAPY"
Anthony Letai et al.
Science, published online October 27, 2011

RESULTS: Researchers at the Dana-Farber Cancer Institute found that tumor cells were more likely to respond to chemotherapy if they were on the verge of apoptosis, which is one of the ways that cells die. In addition, they found that an experimental drug under development by Abbott Labs, which drives cells toward apoptosis, makes cells more sensitive to three different chemotherapy drugs.

WHY IT MATTERS: The findings show that some tumors are closer to apoptosis than others. This information could help doctors identify those patients most likely to respond to chemotherapy, which can have toxic side effects. It could also help scientists develop drugs that make chemotherapy more effective by pushing cancer cells toward apoptosis, a natural part of the cell life cycle that is known to go awry in cancer.

METHODS: Researchers collected live cancer cells from patients with multiple myeloma, acute myelogenous leukemia, and ovarian cancer. They then exposed the cells to protein fragments that promote apoptosis. In the cells that were already close to death, these fragments damaged the mitochondria. The researchers correlated the degree of damage with the patients' response to chemotherapy.

NEXT STEPS: Anthony Letai, the researcher who led the study, has cofounded a startup called Eutropics Pharmaceuticals, which has licensed the technology and is planning clinical trials in cancer patients.

INFORMATION TECHNOLOGY

Stealth Texting

Touch screens that work through fabric

SOURCE: "POCKETTOUCH: THROUGH-FABRIC CAPACITIVE TOUCH INPUT"
T. Scott Saponas et al.
Proceedings of the 24th ACM Symposium on User Interface Software and Technology, Santa Barbara, California, October 16–19, 2011

RESULTS: Researchers at Microsoft created a touch screen that can be operated through fabric. The system, dubbed PocketTouch, was incorporated into a prototype mobile device that could be operated while still in a user's pocket. If a person's phone rang during a meeting, a rapid touch gesture could silence it or send a particular text message in response. The system worked through 23 different fabric types, even the thick fleece of a winter jacket.

WHY IT MATTERS: Although touch screens have become the default mode of interaction for mobile devices, they have drawbacks compared with traditional buttons. A conventional touch screen rejects any signal it detects that is not strong enough to have come from direct contact, which is why it can be frustrating to try to use one while wearing gloves. The Microsoft work shows that improvements to touch-screen technology could replace the lost functions left behind with traditional buttons.

POCKET TOUCH This prototype touch screen can detect the swipe of a finger through different types of fabric.

METHODS: The PocketTouch prototype was built by mounting an off-the-shelf touch sensor to the back of a smart phone's case. Unlike existing touch screens, it has specialized software that can tune the sensitivity of the sensor to compensate for the thickness of the fabric covering it, helping it detect a clear signal through the fabric.

NEXT STEPS: The researchers will refine their prototype after testing it against different types of fabric. For practical reasons, the device also needs a way to detect automatically when it should shift between direct-contact mode and responding to touches through fabric (the prototype is always in fabric mode). It might do that by tracking ambient light levels, which most smart phones already do to tune display brightness. Another possibility would make use of new kinds of optical sensors.

Monitoring Depression

Surveillance with in-home sensors can track a person's mental state

SOURCE: "EMPATH: A CONTINUOUS REMOTE EMOTIONAL HEALTH MONITORING SYSTEM FOR DEPRESSIVE ILLNESS"
Robert Dickerson et al.
Wireless Health 2011 Conference, San Diego, California, October 10–13, 2011

RESULTS: University of Virginia researchers developed a combination of in-home sensors and cloud software designed to detect signs that someone is displaying behavior consistent with depression. One home was outfitted with sensors that report on the user's sleep quality and body weight. It also registered when the person was at home and tracked movement inside the house. Software can combine the data gathered by those sensors into a "depression index" that could signal to caregivers when a person may need help to prevent or overcome an episode of depression.

WHY IT MATTERS: According to the World Health Organization, depression affects about 121 million people worldwide and often goes undiagnosed. Using sensors to monitor at-risk people for early signs of depression, such as poor sleep and less time spent going out or on housework, cooking, and personal hygiene, could lead to much earlier detection and treatment. This approach is well suited to the care of elderly people who live alone; it is estimated that more than 15 percent of people over 65 have symptoms of depression. The researchers suggest that their design might also help soldiers returning from combat, who are at risk for post-traumatic stress disorder. While wireless health-tracking technology is increasingly common, until now it has been used only to record direct physical attributes such as heart rate, not to follow a person's mental state.

METHODS: The sensors took only an hour to install in a patient's home and cost less than $800. The researchers installed wireless motion sensors on the bed to monitor movements during sleep, Wi-Fi-capable scales that track body weight, and sensors on doors and in rooms to track movement. An app for the patient's cell phone periodically asked questions about mood and tracked voice characteristics. All this information was transmitted over the Internet to software that calculates a depression index and can also provide more detailed information to caregivers.

NEXT STEPS: The researchers plan to refine the system so that it tracks social interactions. They also intend to add a component that can monitor a person's speech over time for features related to mood, and trials on more people at risk for depression are planned as well. tr

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Keeping Up with the Despots

One columnist wondered whether democracy was nimble enough to compete with tyranny.

By TIMOTHY MAHER

HEAD START? The head of the "Spirit of the Soviet Worker" is hoisted atop a 79-foot-high statue at the Soviet Union's exhibit at the 1939 World's Fair in New York.

NEW YORK DAILY NEWS VIA GETTY IMAGES

Can an open democracy develop and adopt new technologies as well as an authoritarian state can? It's a question we might ask today, given China's transformation over the past decade into the leading manufacturer of solar panels and other emerging technologies (*see "The Chinese Solar Machine," p. 46*).

The question was just as valid in April 1940, when a *TR* columnist named Stuart A. Rice wondered—in a piece called "How Efficient Is the State?"—whether dictatorial states such as Germany and the Soviet Union were leapfrogging the United States precisely because they weren't free. Rice asked: "Is democracy efficient enough as an organizing principle among people who have reached our own level of scientific attainment to compete on equal terms with the organizing principle of dictatorship?"

In analyzing this question, I wish to make the comparison as the scientist or engineer would make it, uninfluenced by the predilections for democracy which I avow ... Can democratic institutions hold their own in the present struggle for survival between them and the institutions of authoritarian nations?

Rice felt that authoritarian states held a clear short-term advantage—they could adapt quickly, simply by deciding to. They weren't weighed down by checks and balances or slowed by debates. Nor did they rely on the willing participation of their citizens.

They are not impeded in their adaptation of means to ends by the accumulation of habits, conventions, prejudices, and superstitions which retard the utilization of new methods by individuals who are left to make their own decisions. Authoritarian states have the ability to shorten what Ogburn has termed the "social lag."

Sociologist William F. Ogburn, in 1922, had used this term to describe the interval between the introduction of new technologies and a society's adjustment to them. That time lag could be crucial, Rice felt, because a motivated authoritarian state just might crush a democracy before it had time to react. The trick for a democracy, then, was to emulate a dictatorship in that one regard only—it should learn to be more nimble in the face of technological change.

The key questions for Rice were ones we're still lobbing back and forth today: should the government sit back and let the free market develop innovations on its own? Or should it act as a guiding hand?

To put it in today's terms, does a hands-off approach make sense when governments in China and elsewhere are spending billions to support and promote new startups, factories, and technologies? The failed $535 million loan to Solyndra, a solar-technology company, has become a massive political liability for green-tech advocates in the United States. Meanwhile, the Chinese government—even if it doesn't exercise as much state control as Nazi Germany or the Soviet Union did—doesn't face such obstacles. It simply finances whatever it wants to finance.

It is said that "government interference" with business is a threat to democratic institutions and an evidence of totalitarian tendencies. I suggest, on the contrary ... that government concern with the operations of the economy reflects a strain toward the adaptation of social institutions to science; that it is necessary to the attainment of efficiency in a democracy.

The good news, in Rice's view, was that an open society held all the long-term advantages. Innovation over the long haul, he felt, required incentives, competition, and the freedom to debate new ideas and dream of unlikely things: "Science and intelligence are themselves among the materials rendered inert when placed beneath the yoke."

I believe that democracy and science are native allies. It is only in a democracy that the basic conditions of continued scientific progress can be provided. Dictatorship is destructive of intellectual integrity, of freedom to pursue scientific interests without interference, and of that essential exposure of the work of the scientist to the free winds of competent criticism. tr

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